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ABSTRACT

Guidelines are presented for achieving the human factors inputs to the TA (Technical Approach) in the design process. (For each Navy training device, a TA determination provides for the evolution of the necessary technology.) A method is described which allows correlation of instructional requirements with engineering design solutions. The three major sections are: 1) techniques for deriving the information requirements relative to achieving simulation fidelity in trainee station design; 2) procedures for deriving the information requirements involved in setting up, controlling, monitoring, and evaluating performance at the instructor station; and 3) human factors test and evaluation requirements in the training device acceptance process. These are organized to assist the human factors specialist in determining that the device performs as advertised. (Author/JK)

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Technical Report: NAVTRAEQUIPCEN 71-C-0013-1

TRAINING DEVICE DESIGN: HUMAN FACTORS REQUIREMENTS IN THE TECHNICAL APPROACH

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ABSTRACT

This report presents guidelines for achieving the human factors inputs to the Technical Approach in the training device design process. A method is provided which facilitates the correlation of instructional requirements with engineering design solutions. Techniques and procedures are recommended for organizing the information requirements which must be accounted for in the engineering design in order to maximize the instructional potential of a device.

Three major sections are provided. The first of these presents techniques and procedures for deriving the information requirements relative to achieving simulation fidelity in trainee station design.

The second section presents procedures for deriving the information requirements involved in setting up, controlling, monitoring and evaluating performance at the instructor station. Fourteen chapters describe the information requirements pertinent to the structure and control of training during the off-line, pre-mission, enroute training and post-exercise operations.

The last section discusses the human factors test and evaluation requirements in the training device acceptance process. Procedures are outlined for verifying the suitability of a training device as an instructional system. The test, evaluation and demonstration requirements throughout device fabrication are organized to assist the human factors specialist in determining that the device performs as advertised.

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FOREWORD

A previous report in this series "Human Factors Inputs to the Training Device Design Process", NAVTRADEVCEN 69-C-0298-1, discusses the Human Factors role in the specification of requirements for training devices and presents substantive information for use in this process. This present report takes up where the previous left off. The interactions between Engineering and Human Factors specialists in trainee station and instructor station design and evaluation are described and exemplified.

Vincent J Sharkey

VINCENT J. SHARKEY
Scientific Officer

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SECTION I

INTRODUCTION

1. INTRODUCTION

1.1 BACKGROUND. The Naval Training Device Center Technical Approach determination (TA) provides the technical description of a training device in response to the Military Characteristics (MC) description of the device. Whereas the MC provides the initial documentation and describes the training need and the training situation (NAVTRADEVCEN INST. 3910.4, 1969), the TA provides for the evolution of the technology (NAVTRADEVCEN INST. 3910.5, 1970). Both accomplish their goals through the incorporation of concept, detailed and production cycles (i.e., the concept TA responds to the concept MC, the detailed TA responds to the detailed MC, the production TA responds to the production MC). This process has been developed to provide a properly planned, described and costed presentation for a proposed training device. The training device development chronology is thus: MC, TA, procurement package. All phases require substantial human factors support and consultation.

The Technical Approach is utilized to provide specific engineering concepts, development plans and cost estimates prior to the preparation of the procurement package for the training device. The documentation describes how the device will be developed, fabricated, acquired and supported. Developing the Technical Approach (and preparing the report) is the responsibility of the engineering group. The objective of a TA is to develop sufficient engineering details and alternatives to enable a training agency to evaluate systematically the merits of funding a training device. The TA phase is predicated on an existing data base; the functional training characteristics required to provide the desired training capability have already been derived.

At present, there is no routinely used acceptable human factors procedure for determining the technical approaches to training device design (i.e., detailed information on how a device should be configured to achieve the desired training approach). Each device is handled in terms of its own objectives and frequently, the human factors inputs are inadequate or incomplete.

1.2 PURPOSE. This report presents a guide for achieving the desired human factors inputs to the Technical Approach determination in the training device design process. It centers on the issues of human factors responsibility in device design, specifically, on the instructional requirements that must be fulfilled via engineering implementation. The human factors role is to specify the information requirements that must be accounted for in design in order to maximize the instructional capability of the training device.

A method (techniques and procedures) is provided for systematically examining the relationships between alternative training system configurations and desired student performance. This method is set in a framework which facilitates the correlation of instructional requirements with engineering options in the training device design process. In addition, guidelines are organized for identifying and examining the relevant design alternatives at the man-machine interfaces to assure the most effective instructional capability for the costs involved. In essence, this report represents a means of solution testing for subsequent engineering design to insure an instructional capability consistent with the training purpose and the training objectives articulated for a proposed device. The organizing methodology outlined in this document may be viewed as a contribution to the design process.

1.3 PERSPECTIVE. The techniques and procedures described in this report are designed to support the engineering group by providing means for assuring that proposed engineering solutions will optimize the instructional capability of a contemplated training device. Guidelines are organized to assist the human factors specialist in interacting substantially with engineers in deciding on the utility of alternative technical approaches and on the final design selection. These guidelines provide a structure (design pathway) for the development of the information requirements for simulation fidelity in trainee station design and for achieving an instructional capability for shaping desired behaviors via instructor station design. Specifying the information requirements for achieving effective instruction is the primary theme of the human factors support. This report provides assists which enable the human factors specialist to "arm himself" with the information requirements that should be accounted for in engineering design prior to any formal interactions with the project engineer in developing the technical approach documentation. In other words, the content of this report is devoted to the various human factors analyses that should be completed as a prelude to formal interactions between engineering and human factors in examining alternative engineering solutions for achieving the desired instructional capability within cost and lead-time expectations. This emphasis is most consistent throughout the report; the additional interaction requirements are merely outlined, leaving the actual design process to be accomplished within the procedures established by the engineering codes. This is in keeping with the support role provided by human factors in technical approach documentation.

The procedures and formats described here pertain to the development of the technical approach for any contemplated training device. As such, they may at times suffer in desired specificity for a given design effort. However, the guidelines approach enables the known facts and the constraints to be systematically arranged for most design situations and this provides a basis for examining engineering alternatives for achieving instructional strategies consistent with design concepts for a range of training device classes. The feature that the human factors design analysis and tradeoff determinations are organized prior to any formal interaction with engineers makes possible the most economical and fruitful subsequent interaction for examining the relevant engineering solutions to defined training problems.

The starting point for this guidelines development is the MC Documentation. The techniques and procedures described in this report are anchored to the MC for the contemplated device and implicitly assume a consistent referral to the MC for design direction. Thus, it is tacitly assumed that the appropriate background effort specifying the functional requirements for a contemplated training device has been completed as a prelude to the TA documentation. This includes: the articulation of the purpose of the training device; a description of the nature of, and the performance characteristics of the counterpart operational system; the task structure and training objectives; gross device definition; the functional characteristics of the trainee station environment and the instructor station requirements; the anticipated student population; and the training schedule and the anticipated total instructional time allotted per student or team.

A basic question concerns the manner in which human factors inputs are made to the Technical Approach documentation. In essence, human factors support is provided the project engineer through the systematic analysis of the information requirements for achieving the desired instructional capability in the following:

> Trainee station--this effort considers the extent to which task elements must be simulated, their relative importance and criticality for training (clarification and the setting of the limits of fidelity) to the detail required to determine cost and lead-time estimates in software and hardware. This includes a justification for the provision of the selected simulation elements vis-a-vis instructional value. Where applicable, an examination is also made of the means available (i.e., candidate engineering solutions) for best meeting the simulation requirements.

> Instructor station--this effort considers the display, control and communications requirements for the problem installation, monitor, control, evaluation and critique functions involved in training.

How this is accomplished is treated in detail in the subsequent sections of this report. The outputs of this effort are incorporated by the engineering group into the technical approaches deemed feasible for achieving the design requirements specified in the MC documentation.

1.4 ORGANIZATION OF THE REPORT. This report is written expressly for individuals charged with the responsibility for human factors inputs during the conception and development of the design of training devices. It is also envisaged to be of interest to simulation engineers involved in developing the technical approach and the subsequent specification package for any contemplated training device.

The material presented does not conform to the table of contents of NAVTRADEVCEN INST 3910.5, Preparation of Technical Approaches for Training Devices. Instead, it is organized as a logical approach for achieving the human factors requirements specified in the instruction and corresponds most closely to the order in which the design effort should actually be accomplished. It also provides considerable detail in technique and procedure for achieving what we consider to be the requisite human factors contributions to TA documentation as specified by the gross categories outlined in the Instruction.

Three major sections are presented in addition to this Introduction. Section II presents procedures and techniques for deriving the information requirements relative to trainee station design; Section III organizes the control, display and communications requirements relevant to instructor station design; Section IV presents the information requirements for the evaluation of training system design.

SECTION II

TRAINEE STATION DESIGN

2. INTRODUCTION

An output of the MC defines the extent and levels of simulation needed to achieve the purpose of the training for the contemplated training device. This includes decisions on those portions of the operational system counterpart which will be represented, the training system configuration, the system suites (i.e., core equipments needed to operate analogous to the operational system), the device operating modes, as well as the design considerations associated directly with providing flexibility in developing the required instructional strategies.

The effort now is to specify precisely the simulation requirements and appropriate fidelity levels for the contemplated training device. Decisions on what must be simulated and the design options available within the state-of-the-art together with costs constraints are anchored to the functional specifications of the MC. The design criterion is clear: provide the means for exercising and developing the human performances required in the operational environment. The human factors specialist is concerned with deriving the information requirements that must be satisfied in representing the synthetic environment in which training is conducted. Trainee station design considers most prominently the issues involved in achieving simulation fidelity, that is, specifying the displays, controls and communications involved in the device and the fidelity levels required at the man-machine interfaces, ranging from high fidelity in engineering simulation to deliberate departures from reality involving special features of design not found in the operational system, in order to enhance learning. Of concern is the extent to which certain events must be simulated and their relative importance and criticality for training.

The human factors input centers on the definition of the simulation elements which should be accounted for in design. These represent the parameters and their values (range, envelope, number) needed to accomplish the desired training, hence govern the range and complexity of task installation in the device. The simulation elements which are controllable (manipulated or modified manually or automatically via the instructor station) determine the perceptual equivalence of the training environment and the operational situation. The ability to provide the desired training in the identified tasks is directly dependent on the availability and adequacy of these simulation elements in a training device (i.e., which ones are selected and how usefully they are represented). Shortcomings in the simulation of these elements define the shortcomings in the training capability of a device. The simulation elements are associated with the representativeness and complexity of the tasks to be trained in the device.

Thus, the design effort centers on:

- a clarification and a setting of the limits of fidelity (i.e., a correlation of engineering design with the MC requirements for the contemplated training device).

- equipments and software requirements that are specific to the training device. This concerns aspects of the training situation not dictated by the operational system (i.e., equipment and display items provided in addition to the vehicle compartment or cockpit configuration for enhancing the instructional capability).

Minimal analytic emphasis is placed on design features specified in the MC for which engineering design practices are relatively fixed so far as fidelity is concerned (regardless of the adequacy of the current engineering state-of-the-art). These include such capabilities as platform motion, radar land mass, and control forces simulation. Human factors contributions in these areas cannot be made within the time frame of the technical approach documentation. Significant improvements in representing these and similar design options require additional and often substantial research (see Section IV). Thus, where needed human factors data are lacking, the design practices within the current engineering state-of-the-art are tacitly accepted so far as human factors support is concerned, and no additional input is provided beyond the decisions made in the MC.

2.1 RATIONALE FOR HUMAN FACTORS INVOLVEMENT IN TRAINEE STATION DESIGN. The human factors effort centers on the information requirements that must be accounted for in any training device design approach. The engineer requires data which specify how much of and how well the tasks should be represented in order to determine the relevant alternative technical approaches, one of which will ultimately be selected for mechanization. The human factors contribution includes a depiction of how many parameters are needed and in what form in order to represent the task, i.e., what simulation elements must be provided to achieve the purpose of training and the training objectives for the device. Now, the fidelity issues of what should be simulated in light of the training goals have already been examined in the MC (i.e., what do you want to have happen?). For the Technical Approach, statements are needed setting the adequate levels of fidelity and clarifying the simulation requirements (i.e., in what ways can the desired end results be obtained?). The relative importance or criticality of the simulation elements for training must be described. Critical simulation elements are those which exert an appreciable effect (based on the best available evidence) on rate of learning or on level of proficiency. This information on fidelity requirements is provided in the detail needed (i.e., the extent of, and criticality of the simulation elements to be represented with a justification of why an element is important for training) to permit costing and lead-time estimates to be made. Armed with these data, the human factors specialist can support the engineer in justifying the inclusion of the relevant simulation elements for the costs incurred, and in decisions on optimum ways for mechanizing those requirements including, as applicable, an examination of candidate engineering solutions. What to mechanize must be finally selected in terms of costs and lead-time vs. training effectiveness (defined by the ability to meet or extend the achievement of the training objectives outlined in the MC).

2.2 BASIC APPROACH. Various techniques and procedures are provided as guidelines for analytically determining the information requirements and the instructional capability that must be represented in design. For human factors, fidelity has meaning in terms of the training process and the realism necessary to promote transfer of training. Defining the design characteristics for maximizing transfer of training from the synthetic environment to the operational requirement revolves essentially about two interrelated questions: what or how much should be simulated, and how well should this be represented in terms of degree of physical correspondence to the operational environment? These two questions plus the concern for incorporating training technology into design (integrating training process with engineering fidelity) circumscribe the approaches to fidelity. The fidelity decisions must necessarily consider the monetary costs and the lead-time problems entailed and what the omission of critical simulation elements will cost in training effectiveness. Some assistance in this determination is provided in this document.

In essence, guidelines are provided the human factors specialist by means of detailed techniques and procedures which serve in organizing the simulation elements crucial to engineering design. These information requirements formats, once completed, can be effectively employed by the human factors specialist in interacting with engineers to examine candidate engineering solutions and to compare relevant technical approaches in terms of training effectiveness, costs, and lead-time constraints. These techniques and procedures are described in detail next.

2.3 TECHNIQUES FOR ACHIEVING HUMAN FACTORS INPUTS TO TRAINEE STATION DESIGN. The basic theme of the human factors effort is to determine the information requirements which engineering must account for in proposing alternative technical approaches to trainee station design. This concerns the definition of the simulation elements to represent and the criticality of these elements to training, the levels of fidelity to implement and specifying techniques for instructional control in order to achieve the training capability defined for the training device. Four variations on this basic theme are described below. These provide techniques and procedures that are pertinent to a range of training device design situations.

The need for this variation recognizes that information requirements for design will vary as a function of classes of training device both in terms of the operational requirements (e.g., flight, surface, subsurface) and the trainee personnel (e.g., multiple and interdependent students such as in tactical team training; individual students such as in an OFT; and multiple but independent students such as in group training for a given specialty). Thus, the four distinctive techniques provide guidelines for deriving the human factors simulation requirements applicable to a range of training device design situations. The reader needs but to discern which of the cases is applicable to his specific design strategy and apply the guideline procedures, as applicable.

The four techniques are the following:

Case 1: Technique for deriving information requirements and setting the limits of simulation fidelity.

Case 2: Technique for correlating candidate engineering solutions with simulation requirements.

Case 3: Technique for defining display and control requirements in generalized trainee station design.

Case 4: Procedures for employing instructional technology to enhance training capability.

2.3.1 CASE 1: Technique for deriving information requirements and setting the limits of simulation fidelity.

A basic human factors effort is to identify the simulation elements to be represented for training, for these define the device hardware and the software programing requirements. At stake are the following: How much to simulate and what levels of fidelity to provide (with the implicit cost-effective question of what may be omitted from complete fidelity of representation without significant decrease in training value). The simulations engineer needs to know what and how many parameters must be simulated and the fidelity requirements in order to adequately represent the task for training.

The identification of simulation elements (i.e., those factors to be simulated that determine the representativeness and the complexity of the tasks to be installed for training), and the parameter values (range, envelope, number), are crucial inputs to the definition of fidelity. These must be clearly specified in order to achieve the required device configuration to enable training to the level expected. In short, the simulation elements define what is needed in the synthetic environment to achieve the expected transfer of training. The output of this effort is an organization of simulation elements that are relevant to achieving the training purpose defined for the contemplated training device.

The procedure for accomplishing the derivation of the design information is outlined in the following series of steps:

1. Identify the design subsystem or area
2. Identify the training problem--define the task requirements associated with the design subsystem or area
3. Identify the critical simulation elements (information requirements, mission derived); correlate these with acceptable levels of fidelity.
4. Describe the training effectiveness implications of each of the decisions in Step 3. (The procedure thus far is accomplished by the human factors specialist; from here, the human factors specialist interacts substantially with the project engineer).
5. Interact with the project engineer to: justify the simulation elements selected and the fidelity level for the element; correlate the information requirements with alternative technical approaches and engineering implementation; and compare the technical approach choices with cost and lead-time considerations.
6. Support the engineer in documenting the proposed technical approach for the given design subsystems or areas.

These procedures are described in detail next, together with an example selected to provide the necessary analytic guidelines for the reader.

Step 1: Identify the subsystem on operational counterpart to be simulated

The pertinent subsystems involved in any contemplated training device are identified in order to systematically examine the simulation requirements. Within this frame, the major subsystem groupings are organized. Individual analyses are then conducted for each subsystem (as appropriate): sonar, radar, electronic warfare, visual real-world, vehicle control, and weapons in order to derive the simulation requirements specific to each. Within each of the relevant subsystems, the simulation elements are analyzed and organized independently in terms of: own-vehicle and support units; targets; and media characteristics. Figure 1 depicts these relationships in matrix form.

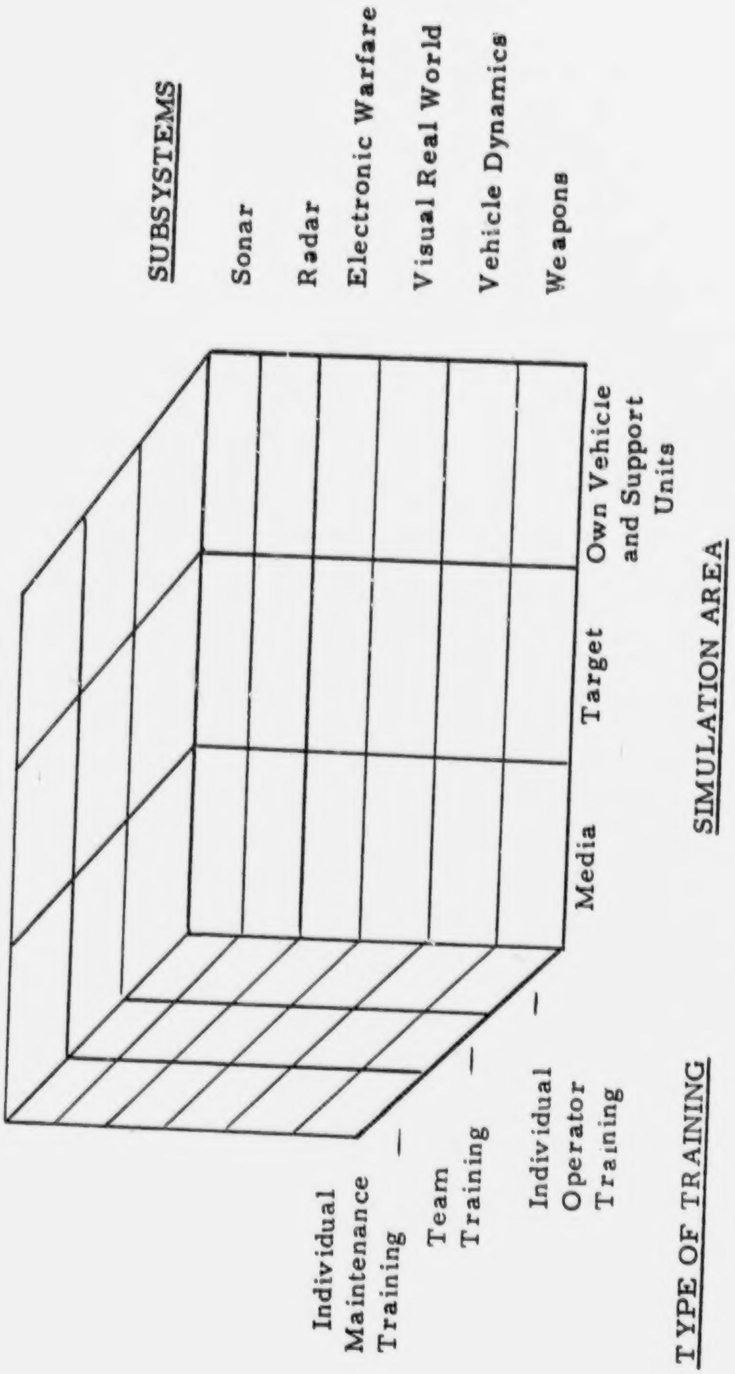

Figure 1. Simulation Elements Matrix

Step 2: Identify the task requirements associated with the design subsystem or operational counterpart

The task structure provides the clues for determining what must be simulated for training. The range of task requirements influences the decisions on what and how many parameters should be installed in the training environment. Table 1 presents a major grouping of task structure (involving mission/vehicle combinations) appropriate to the design areas identified in Step 1. For each of these task groupings, detailed task analysis data are required in order to specify the simulation elements required. (It is assumed that this detailed information is available from the training requirements analysis conducted during the Military Characteristics documentation phase).

Step 3: Identify the simulation elements to be represented and correlate these with acceptable levels of fidelity

The MC documentation serves as the basis for this essential step in the technique. Training purpose, task structure and the training objectives have already been articulated and decisions have been made on the training system configuration, the system suites that will be represented (e.g., SQS-23 Sonar, Mk 114 Fire Control System), and on the basic fidelity levels desired for classes of training tasks. Since these features of the device are set, specifying the parameters and their values (in hardware terms) which comprise the synthetic environment and their fidelity levels is the next order of business. The identification of the simulation elements governs the range and complexity of task installation in the device and thus influences training effectiveness (i.e., the achievement of training for the defined task structure). The ability to provide the desired training in the identified tasks is directly dependent on the availability and adequacy of these simulation elements in a device (i.e., which ones are selected and how usefully they are represented).

The array of the simulation elements that must be evaluated for representation in the design of the trainee station are organized in terms of own-vehicle and support units, target, and media characteristics. Within each of these three groupings, decisions must be made about the dimensions or levels of fidelity required.

Four levels of fidelity are employed in specifying the characteristics required to insure effective task installation.

Level 1--is defined by high fidelity representation (where the engineering state-of-the-art is adequate). This involves two aspects:

TABLE 1. MAJOR CLASSES OF TASKS APPROPRIATE TO THE ANALYSIS OF SIMULATION REQUIREMENTS

1. SURVEILLANCE
    a. Target acquisition (search, detect, classify, track)
    b. Signal analysis
2. VEHICLE CONTROL
    a. Airborne
        1) Air-to-air environment
            - refueling
            - combat
            - formation flight
            - ASW station-keeping
        2) Air-to-ground environment
            - visual navigation
            - reconnaissance
            - terminal area (takeoff/landing)
        3) Air flight
            - maneuvers
            - vehicle positioning
    b. Surface
        1) harbor navigation
        2) mooring/docking
        3) vehicle positioning
    c. Subsurface
        1) approach/attack positioning
        2) navigation/reconnaissance
        3) casualty/damage control

TABLE 1. MAJOR CLASSES OF TASKS APPROPRIATE TO THE ANALYSIS OF SIMULATION REQUIREMENTS (Continued)

3. WEAPONS DELIVERY

    a. Air-to-surface
    b. Surface-to-air
    c. Surface-to-subsurface
    d. subsurface-to-surface
    e. Air-to-Air
    f. Surface-to-surface
    g. Subsurface-to-subsurface

4. TACTICAL EMPLOYMENT

    a. Tactical decision-making
    b. group/force deployment in tactical engagement

- precise representation of the operational system counterpart (envelop, steps, values, range)
- deliberate backing off from high fidelity (to achieve cost economies without compromising training effectiveness)

Level 2--is defined by the fidelity achievable when reduction in tolerances is required (where the engineering state-of-the-art is less than adequate).

Level 3--is defined by the simulation of generalized/universal functions (which may involve low fidelity representation as well as part-task simulation).

Level 4--is defined by deliberate departures from realism in order to enhance training effectiveness (qualitative deviations from the operational system being simulated).

The derived critical simulation elements are correlated with the required fidelity levels, using the format outlined below.

Critical Simulation Elements	Fidelity of Simulation Levels			
	1	2	3	4
(Task/vehicle combinations)				
• Own-vehicle and support units				
• Target				
• Media				

The classes of simulation elements are grouped within each major subsystem applicable to the device under consideration.

An example of the analytic derivation involved in Step 3 is described next. The example selected concerns the information requirements involved in Sonar Subsystem design (see Step 1). The task structure involves surveillance requirements in an ASW tactical team training context (mission-vehicle combination: Destroyer (DLG, DDG) or Cruiser in ASW operations) (see Step 2). Table 2 presents the derived critical simulation elements

TABLE 2. SIMULATION ELEMENTS AND FIDELITY REQUIREMENTS FOR SONAR SUBSYSTEM DESIGN

Critical simulation elements (information requirements)	Level of Fidelity Required			
	High fidelity (engineering state-of-the-art is adequate)	Fidelity achievable where reduction in tolerances is required (engineering state-of-the-art is less than adequate)	Simulate generalized functions	Deliberate departures from realism (qualitative deviations from the operational system being simulated)
Example: Sonar Surveillance Task (surface ASW vehicle)				
A. OWN VEHICLE AND SUPPORT UNITS				
1. Own-vehicle returns				
• own-ship noise (flow noise, turbine noise)	appropriate video/audio characteristics			
• wakes • knuckles • torpedo hydrophone effects • countermeasures	appropriate video/audio degradation as a function of speed increase correlated with optimum sonar speed; appropriate audio degradation as a			

TABLE 2. SIMULATION ELEMENTS AND FIDELITY REQUIREMENTS FOR SONAR SUBSYSTEM DESIGN (Continued)

	Level of Fidelity Required			
	function of speed increase correlated with optimum sonar speed			
• Cavitation	cavitation sounds detectable when cursor is placed in baffles area			
2. Support unit returns				
• Support ship(s) aspect	Video: appropriate blip size, shape, brightness for the vehicle correlated with aspect Audio: appropriate echo quality, doppler effects correlated with aspect			
• echo ranging effects				
• pings (helo, sub)				
• knuckles				
• wakes				
• noise				
3. Malfunction capabilities	Audio, video failures, complete system failure			
4. PPI Display-- Perceptual Requirements	Characteristics of: echo quality, pip quality (aspect) axis angle, trace length and differential range rate			

TABLE 2. SIMULATION ELEMENTS AND FIDELITY REQUIREMENTS FOR SONAR SUBSYSTEM DESIGN (Continued)

	Level of Fidelity Required			
5. Visual Display Requirements	Acuity, luminance, refresh rate (flicker) contrast, sensitivity, resolution			
6. Transfer of sonar data to fire control subsystem	Range, speed, bearing, target course (manual insert)			
	generated target tracking			
B. TARGET				
1. Target characteristics	Number of targets displayed at a given time			
	classes of targets (and vehicle dynamics)			
	target appearance/disappearance/attenuation as a function of range and sea conditions			
	target movement as a function of range, bearing, aspect changes			

TABLE 2. SIMULATION ELEMENTS AND FIDELITY REQUIREMENTS FOR SONAR SUBSYSTEM DESIGN (Continued)

	Level of Fidelity Required			
2. Target vehicle returns		—		
• aspect (bow, beam, stern)	Video: appropriate blip size, shape, and brightness persistence for brightness modes Audio: doppler effects via increase, decrease, no increase in pitch over transmission frequency			
• cavitation effects	Video: appropriate noise spoke for speed, depth, range, and BT envelopes Audio: appropriate for speed, depth, range and BT envelopes			
• hydrophone effects from torpedo				
• knuckles	Video: appropriate blip size, shape and brightness persistence for brightness modes			
• wakes				
3. Instructional assists				Target enhancement in noise (under instructor control)

TABLE 2. SIMULATION ELEMENTS AND FIDELITY REQUIREMENTS FOR SONAR SUBSYSTEM DESIGN (Continued)

	Level of Fidelity Required			
C. MEDIA				
1. Environment				
• wind direction/ speed	full 360°, 0 - 100 knots-- to affect all air operations and sea states			
• sea state	range 1 to 6 correlated with wind speed to cause degradation on sonar (reverberations)			
• bottom depth	100 - 2000 ft. with bottom characteristics			
• thermal gradient	increments and isothermal			
• land masses	harbor areas			
• ocean area	X-Y coordinate system (64,000 x 64,000 ft.)			
• altitude	0 - 5000 ft.			
2. Range	Envelop of detection ranges achieved operationally (as a function of sea state, layer depth, and target depth and aspect)			

TABLE 2. SIMULATION ELEMENTS AND FIDELITY REQUIREMENTS FOR SONAR SUBSYSTEM DESIGN (Continued)

	Level of Fidelity Required			
3. Non-target returns				
• reverberations		Appropriate video and audio characteristics		
• bottom returns			Video: typical soft and hard bottom configurations Audio: appropriate characteristics	
• fish, whales, reefs, pinnacles, wrecks		Appropriate blip size, shape and brightness for brightness modes, appropriate doppler effects, echo quality		
• submarine launched torpedo hydrophone effects	Appropriate audio appropriate noise spoke			

TABLE 2. SIMULATION ELEMENTS AND FIDELITY REQUIREMENTS FOR SONAR SUBSYSTEM DESIGN (Continued)

	Level of Fidelity Required			
• submarine launched false target cannisters, decoys, jammers • own-ship torpedo hydrophone effects • fanfare	appropriate audio and video characteristics			
4. Background clutter and noise on the display	appropriate operational characteristics			

correlated with the required fidelity levels for the Sonar subsystem involving surveillance requirements in ASW operations. This provides guidelines for a procedure that must be accomplished for each of the major subsystems pertinent to the contemplated training device.

Step 4: Document the training effectiveness implications of the simulation elements selected for representation

Justification is now provided concerning the instructional advantage of the simulation elements selected and the acceptable fidelity levels. This discussion should also indicate any disadvantages accruing from eliminating certain information requirements and what effects reducing or enhancing the fidelity level will have on the instructional capability. Those simulation elements crucial to the training problem should be identified (i.e., those key information items, if rejected or modified significantly, will impair the instructional purpose of the device, and thus should not be compromised). In addition, the human factors specialist should be prepared, in discussions with engineers, to modify or eliminate selected simulation elements, 1) which may be logically pertinent to the trainee station design, but be of indeterminate training value, 2) which will enhance training value but when weighed against costs to obtain, are excessively expensive to mechanize, or 3) which are not desirable for other than technical reasons.

The justification should be anchored to antecedent MC decisions in terms of overall device configuration, the basic "core" equipments and suites, and the fidelity levels envisaged for the trainer. The MC decisions affecting our sonar subsystem example include the following:

- Sonar is a component of an ASW team trainer,
- Training emphasis is on precedural and tactical decision-making sequences involving coordinated team effort in operating and employing a surface vehicle,
- Specific system suites are required since a direct transfer of training is desired from the device to the operational vehicle (teams will be drawn for training from operational units when in port),
- Compartment spaces, equipments and operating modes are replicas of equipments aboard ship. The physical appearances of key equipments with all operating controls and indicators are the same. For the present example, the relevant equipments are: the AN/SQS-23 sonar and the Mk 53 Attack Director Console,

- The information requirements are based on a high fidelity sonar environment with signal characteristics realistic of the range of real-world events,

- Device configuration must provide a training environment conducive to accomplishing the following: procedures in search and detection; maintenance of contact and tracking; procedures for readying weapons system for attack; utilization of communication circuits; and procedures in the prosecution of targets.

A format for justifying the derived simulation elements for our sonar subsystem example is shown below. Only key concepts and requirements are identified. In actual situations, the narrative should be expanded and include any supporting evidence. The goal is to maximize the flexibility for training in achieving the relevant training objectives.

1. Own-vehicle requirements

The elements identified will provide the necessary realism in sonar displays for achieving the training objectives specified in the MC.

Provision of own-ship wakes and knuckles gives CIC the opportunity to account for these phenomena and to coordinate with sonar to prevent acquisition and tracking of these false targets.

Sonar returns sensitive to vehicle size or aspect are cues to classification.

Target classification capability is crucial to realizing the full potential of the trainer. Classification (false target capability) introduces the element of uncertainty in threat evaluation requiring decisions for dealing with false targets and false contacts and the attendant time losses in determining if the contact is a possible submarine. Lack of classification uncertainty modifies team procedures away from the realism of real-world operations. The presence of classification cues forces a greater decision making requirement on the team and a greater tactical involvement. Sonar subteam skills are also enhanced due to greater whole-task replication in the device resulting in increased involvement and responsibilities.

2. Target

Both conventional and nuclear submarine vehicle dynamics are required (e.g., equivalent of Russian "Fox Trot" and "November" vehicles).

Accelerations and decelerations of nuclear submarines must be realistic in view of the tactical geometry requirements.

Maximum detection ranges corresponding to the full range achieved operationally (realistic as a function of sea state, layer depth and submarine depth and aspect) are mandatory in order to provide necessary training in use of stand-off weapons systems.

False targets and submarine wakes contribute to the classification requirement. With a display of wake, the sonar operator may erroneously "track off" on this trail. It also provides an evasive capability for the submarine in training exercises which emphasize tactical deception and greater own-ship threat evaluation.

Sonar video or audio failures enhance the control of exercise difficulty. A complete sonar failure, for example, would force own-ship to execute a **DEEP CREEP** attack (own-ship vectored in).

3. Media

Sea state range correlated with wind speed will cause degradation on sonar (reverberations). Also, a lack of correlation will produce unrealistic events (e.g., sea state 1, wind speed 22 knots).

Providing a controllable bottom depth from 100 feet to 2000 feet and showing bottom characteristics as well as depicting representative harbor areas permits the achievement of training objectives concerned with shallow water operations.

Absence of non-target returns (false targets) also obviates the necessity for the use of bottom charts and CIC keeping track of underwater obstructions.

4. Summary

For any device situation a clear and precise justification for the simulation requirements is documented, vis-a-vis training flexibility and effectiveness. Again, in the above sonar example, key design features include:

- video simulation--no cleaner nor less flexible than in the operational environment
- capability for deliberately degrading equipment performance
- high fidelity signal characteristics
- provision of the parameters associated with uncertainty in target identification (classification function).

This procedure (Case I) is replicated for all of the pertinent subsystems in the contemplated training device. When completed and integrated, the number of, and values for the simulation elements have been identified sufficient for installing the environment for training.

> NOTE: The steps described thus far are accomplished by the human factors specialist utilizing the MC documentation and other data available on the contemplated device. When the information requirements analysis is completed, the human factors specialist works in close interaction with the cognizant engineer(s) to complete the procedures involved in determining the simulation requirements in trainee station design. Thus, beginning with Step 5, the output reflects the combined efforts of human factors and engineering.

Step 5: Correlate the information requirements with alternative technical approaches for engineering implementation

The human factors and engineering specialists interact to achieve the following.

- The information requirements are reviewed and accepted, with revisions as appropriate. Justification for the final selection of the simulation elements and the appropriate levels of fidelity is documented.

- The means available for achieving the simulation requirements are identified. This may result in a straightforward engineering approach to the simulation requirements or in several feasible technical approaches involving candidate engineering solutions.

- In the event that engineering choices are available to meet the simulation requirements, the capability of the alternative technical approaches to meet the simulation requirements are analyzed. A matrix format is recommended which enables a comparison of each candidate solution with the simulation requirements. One way of accomplishing this is illustrated in Case 2 of this section. Each candidate technical approach must meet, as minimums, the critical simulation elements (i.e., those that are crucial to solving the training problem).

- For the engineering solutions capable of meeting the defined simulation requirements, costing and lead-time approximations are made.

The design criterion is clear; provide the minimum fidelity of simulation consistent with the training requirements information. The appropriate design options are based on the MC requirements and on the candidate engineering solutions available to achieve the simulation requirements.

Step 6: Provide support in preparing the technical approach documentation

The human factors specialist provides support to the engineering code in preparing the pertinent sections of the Technical Approach documentation as specified in NAVTRADEVCEN INST 3910.5.

Summary

Deriving the information requirements (simulation elements to be represented) and the setting the limits of simulation fidelity is one of the major human factors inputs to the technical approach documentation for trainee station design. The procedure for achieving this is concerned primarily with the human factors derivation of the simulation elements that must be represented in a device to achieve the purpose of the training as articulated in the MC documentation. The output of this effort is applied by engineering and human factors specialists as a basis for developing proposed technical approaches to device design. Figure 2 summarizes the series of steps accomplished in the procedure.

2.3.2 CASE 2: Technique for Correlating Candidate Engineering Solutions with Simulation Requirements

The visual simulation design requirement places a somewhat unique demand on the human factors input because the development of technical approaches is tailored directly to the characteristics of basic visual simulation systems.

A technique[1] is provided here for developing the simulation requirements information necessary for specifying the visual simulation equipment to be used for training. It is an analytic approach designed to: 1) collate the scattered bits and pieces of information about any specific

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[1] This technique was propounded by Dr. Knox E. Miller of the U.S. Naval Training Device Center. A minor expansion of the original formulation is provided here.

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Identify the subsystem or operational counterpart to be simulated	Select the training problem and identify the task requirements (mission/vehicle combinations)	Specify the simulation elements to be represented and the acceptable levels of fidelity (mission derived simulation requirements)	Document the training effectiveness implications of the selected simulation elements (justification for the selection)	Correlate the information requirements with alternative technical approaches for engineering implementation: (interact with project engineer to correlate engineering solutions with simulation requirements)	Provide support in preparing the technical approach documentation

Figure 2. Procedure for Deriving Information Requirements and Setting the Limits of Simulation Fidelity (Case I).

visual simulation problem as seen from the human factors and engineering standpoints, 2) organize this information in a systematic (albeit arbitrary) manner, and 3) display the resulting data in a format which will permit direct comparison of the relative advantages and disadvantages of competing hardware systems. To apply the procedures, the human factors specialist must have a detailed knowledge of the constraints imposed on the hardware selection process by the following factors: a) the characteristics of the operational environment to be simulated; b) the perceptual requirements of the specific mission or mission segment involved; and c) the functional characteristics of the simulation hardware under consideration. The technique should be regarded as a convenient way for organizing and displaying information already available for design. In essence, it consists of a logically based fractionation of visual simulation requirements (derived from (a) and (b) above) on the one hand, and simulation system characteristics on the other, into units of a size which will permit the known facts about each to be arrayed in a series of simple decision matrices. Thus, for each combination of a vehicle/mission segment (e.g., fixed wing, low altitude navigation), and a candidate simulation system (e.g., CCTV model) a number of matrix "scores" can be derived, each of which represents, for a given characteristic, the degree to which the simulation system in question meets the requirements imposed by the specific environment/mission to be simulated. When the individual matrix scores are graphically displayed as a function of the arrayed simulation requirements, a profile is obtained in which the relative strengths and weaknesses of the simulation system under consideration are made readily apparent. Comparison of the profiles derived for each of several candidate simulation systems as a function of the same set of simulation requirements thus provides a logical and objective basis for the selection of hardware.

The procedure for comparing alternative design solutions to the visual training problem is outlined in the following series of steps.

1. Identify the visual simulation problem.

2. Identify the candidate engineering approaches for solving the visual simulation problem.

3. Describe the visual system characteristics which bear on the hardware selection process.

4. Construct a series of matrices correlating visual simulation requirements with system characteristics. (Basically, the procedure thus far is accomplished by the human factors specialist; however, he may interact with engineering in achieving Step 2 requirements. Step 5 is a correlative effort between human factors and engineering specialists.)

5. Develop a system characteristic profile for each candidate engineering approach, depicting the matrix scores for each visual system characteristic.

These procedures are described in detail below, together with examples in order to provide the necessary analytic guidelines for the reader.

Step 1: Identify the visual simulation problem

This involves the selection of the visual simulation problem from a grouping of visual problems pertinent to the NTDC training device inventory. Although the number and variety of potential visual simulation problems is large, those associated with vehicular control are most prominent. These can be logically classified and organized in terms of a) the operational environment (e.g., air-to-ground, waterborne, etc.), b) the type of vehicle (fixed-wing, surface ship, etc.), and c) the mission or mission segment (e.g., low altitude visual navigation, harbor navigation, etc.) which they represent. The remainder consist of artificial sensor display (radar, sonar) problems and a few special cases which are distinct from, but so closely related to, visual simulation that they are often considered under the same heading. The classification scheme adopted for the purpose of this analysis is presented in Table 3. This particular classification is useful because it permits the total mission for a given weapon system to be broken down into meaningful segments, each of which is well enough defined to be dealt with on an analytic basis. For example, a carrier-based attack aircraft on a strike mission might conceivably involve several of the individual mission segments shown in Table 3, each of which has implications for the simulation hardware to be employed. Simulation of the complete strike mission (including carrier takeoff and landing, low altitude visual navigation, target acquisition, weapons delivery, etc.) therefore, requires cascading of the analytically determined hardware constraints associated with each of the mission segments involved. Such progressive restriction of alternative solutions quickly reveals that there is at present no single technique capable of providing a satisfactory solution to the requirement for a total strike mission simulator. But more importantly, this technique can be used to reveal the extent to which various mission segments (part-tasks) can be combined in practical and reasonably cost-effective training equipment.

Step 2: Identify the candidate engineering approaches for solving the visual simulation problem

The number of engineering approaches available to solve the problems defined by the selected mission segments is limited. These approaches are listed in Table 4. This listing is not inviolate; the intent is to include all of the various technologies which have or can be used to

TABLE 3. MILITARY VISUAL SIMULATION PROBLEMS

I. Vehicle Control Problems

  A. Airborne Vehicles

    1. Air-to-Air Environment

      a. Fixed Wing

        (1) Combat Maneuvering
        (2) Air-to-Air Refueling

      b. Rotary Wing

        (1) Tactical Formation Flying
        (2) ASW Station Keeping

    2. Air-to-Ground Environment

      a. Fixed Wing

        (1) Visual Navigation
        (2) Visual Reconnaissance
        (3) Target Acquisition
        (4) Weapons Delivery

          (a) Bombs
          (b) Visually guided missiles
          (c) Gunnery

            1. Fixed
            2. Flexible

        (5) Takeoff/landing (fixed base)

          (a) Night
          (b) Day

        (6) Takeoff/landing (carrier-based)

          (a) Night
          (b) Day

      b. Rotary Wing

TABLE 3. MILITARY VISUAL SIMULATION PROBLEMS (Continued)

(1) Visual Navigation
(2) Visual Reconnaissance
(3) Target Acquisition
(4) Weapons Delivery

(a) Visually guided missiles
(b) Gunnery (flexible)

c. Remotely Controlled (TV guided) Missiles

B. Surface Vehicles

1. Land Based Environment

a. Off Road Vehicles

(1) Tanks/tracked Vehicles
(2) Air Cushion Vehicles

b. Conventional Vehicles

2. Waterborne Environment

a. Surface(d) Ship Control Problems

(1) Harbor Navigation
(2) Ship/submarine Mooring
(3) Ship/submarine Docking
(4) Ship-to-Ship Underway Replenishment

b. Small Boats and Special Purpose Waterborne Vehicles

(1) Assault Boats
(2) Hydrofoil

C. Subsurface Vehicles

1. Subsurface-to-Surface Environment (Periscope Simulation)

a. Approach/attack
b. Reconnaissance
c. Navigation

2. Subsurface Environment (in-water simulation)

TABLE 3. MILITARY VISUAL SIMULATION PROBLEMS (Continued)

II. Artificial Sensor Display Problems

- A. Radar/radar landmass
- B. Sonar
- C. IR
- D. TV-Data Link
- E. ECM
- F. Compound types

III. Special Information Display Problems

- A. Status and Large Area Tactical Information Displays

TABLE 4. BASIC VISUAL SIMULATION SYSTEMS

1. Optically Viewed Models
2. Closed-Circuit TV Viewed Models
3. Point Light Source - Transparency
4. Open-Loop Movie
5. Servoed Projections
6. Semi-Closed Loop (VAMP) Movie
7. Computer-Generated Display
8. Flying Spot Scanner - Factored Transparency
9. Laser/Holographic Displays
10. Hybrid Systems

generate, store, transfer and display imagery for the purposes of visual simulation. The successful application of this technique requires an adequate knowledge of the relative strengths and weaknesses of the simulation hardware available. At the very least, the human factors specialist must understand the major advantages and disadvantages of each of the competing systems under consideration (as a prelude to the subsequent interaction with the engineering code).

It is not our purpose to present an exhaustive analysis and detailed comparison of the specific characteristics of each of these systems. Rather, it is assumed that the reader either possesses or has available to him the background information required to relate these system characteristics to the perceptual requirements of the training situation. However, it is desirable from the standpoint of orientation to review briefly the principal features of each basic system.

1. Optically viewed models
   - a. Typical application - periscope view simulation.
   - b. Primary advantages - high resolution, closed-loop operation, realistic cues to depth, true colors available.
   - c. Primary disadvantages - low brightness, narrow angle of view, difficult scaling problems.
2. Closed Circuit Television - viewed models
   - a. Typical applications - air-to-ground target acquisition, carrier landing.
   - b. Primary advantages - moderately high resolution at moderate brightness levels, closed-loop operation, realistic depth cues, electronic manipulation of imagery possible (raster shrinking, video insertion, selective blanking, etc.).
   - c. Primary disadvantages - narrow angle of view, difficulty in achieving flexible scaling.
3. Point Light Source and Transparency Systems
   - a. Typical application - approach and landing simulators.
   - b. Primary advantages - extremely wide angle field of view available, closed-loop operation, full color easy to provide.

c. Primary disadvantages - low resolution and low brightness, poor depth cues, difficult scaling problems.

4. Open-Loop Movie

a. Typical application - low altitude navigation and target acquisition simulators.

b. Principal advantages - high-resolution, high brightness, full color, extremely wide angle of view, good depth cues available, scaling inherent in film.

c. Principal disadvantages - open-loop operation, difficulty in acquiring adequately controlled imagery.

5. Servoed Projections

a. Typical application - Redeye Moving Target simulator.

b. Primary advantages - high resolution, high brightness, extremely wide angle field.

c. Primary disadvantages - reversed contrast of targets (target appears as bright image against dark background), open-loop operation.

6. Semi-Closed Loop (VAMP) Movie

a. Typical application - takeoff and landing simulators.

b. Principal advantages - high resolution, high brightness, full color, good depth cues, scaling inherent in film, semi-closed loop capability permits limited maneuvering within a narrow envelope.

c. Principal disadvantages - deliberately introduced optical distortion, difficulty of acquiring proper imagery.

7. Computer Generated Displays

a. Typical application - takeoff and landing, air-to-air combat maneuvering, ship docking and station keeping, etc.

b. Principal advantages - closed-loop operation, scaling inherent in programing, independent motion available within visual field, resolution and color elements can be differentially apportioned according to areas of interest, entire simulation problem can be changed or the elements within a problem updated by programing.

c. Principal disadvantages - relatively high system and software costs, imagery consists of line drawings or discontinuous cartoon-like figures.

8. Flying Spot Scanner - Transparency Systems

a. Typical application - radar landmass simulators.

b. Principal advantages - closed-loop operation, method of reading out information (density along narrow beams sequentially scanned by a small spot) produces very good analogue of a scanning radar beam.

c. Principal disadvantages - resolution poor at low simulated altitudes, high cost of producing properly coded transparencies at scale factors required.

9. Laser/Holographic Displays

a. Typical applications - high brightness, large screen tactical situation displays, carrier landing simulators.

b. Principal advantages - very high brightness, multiple colors, and variable persistance of photochromically recorded laser images makes them ideal for large screen status displays. Three dimensional quality of holographic imagery is valuable in simulating carrier landing, ship docking, etc.

c. Principal disadvantages - narrow angle available with holograms, monochrome images, experimental nature of current technology.

10. Hybrid Systems (employing a combination of two or more of the basic approaches outlined above).

a. Typical application - visual mission, for example, simulator utilized in the A-7D weapon system trainer. This proposed system provides visual simulation for takeoff, low altitude navigation, target acquisition, weapon delivery and landing, by incorporating the basic characteristics of a transparency based terrain model, and a semi-closed loop (VAMP-type) projection system.

b. Principal advantages - high brightness, high resolution, full color, semi-closed loop capability.

c. Principal disadvantages - narrow angle of view, cumbersome solution to scaling problems (necessity for repeated alternation of imagery stored in film cassettes), at least seven separate sources of distortion whose effects cumulate in unpredictable ways.

The simplified summaries presented above can be questioned in specific instances. For example, it could be argued that TV-based systems are not necessarily limited to narrow fields of view. However, in order to achieve a wide field, one must sacrifice both resolution and brightness or accept the problems inherent in achieving and maintaining image registration in multiple adjacent displays. Similarly, it could be pointed out that the narrow angle of view which is characteristic of optically viewed systems is not a serious disadvantage in periscope view simulations. In this case, the angle of view is a disadvantage of the general system type, though not in the application cited.

In listing the relative advantages of the various systems, two different types of features are cited. Features such as resolution, brightness, distortion and displayed angle of view are usually considered basic parameters of any visual simulation system. Other features such as the ability to provide independent motion of targets within the visual scene, the relative difficulty in making changes in the stored imagery and whether or not the image storage medium is capable of providing adequate cues to depth are not ordinarily thought of as system parameters. Although the distinction between them is somewhat arbitrary, it is a significant one since an important aspect of our technique is that it deals explicitly with those factors which are crucial in the selection of simulation hardware but which are not recognized as quantitative system parameters. These are the somewhat nebulous, difficult to quantify, but highly important considerations which are usually a product of one's experience. As such, they often play a decisive but implicit role in the decision-making process. The basic problem with such experientially-dependent decisions lies in the individual variations in the implicit definitions of these factors and in the relative weights assigned to each. By explicitly defining as many of the system characteristics which bear on the hardware selection process as possible, this analysis enables the engineering team to arrive at their decisions on a more logical basis.

Step 3: Describe the visual system characteristics which bear on the hardware selection process

The visual system characteristics pertinent to the selection of engineering approaches must be identified. Twenty-three visual factors are listed below and discussed in terms of their criticality to design.

Scaling
Resolution
Detail Required
Color
Absolute Brightness
Contrast Range
Distortion Tolerance
Flicker Tolerance
Accommodation to Infinity
Relative Motion
Independent Motion
Coupled Motion
Programed/Unprogramed
Angle of View
Depth of Field
Ease of Change
Monocular Movement Parallax
Interpositioning
Physical Size
Power Consumption
Original Hardware Cost
Original Software Cost
Maintenance Cost

Scaling. This characteristic is concerned with the degree to which the medium used to store visual information is able to provide a simulated maneuvering area sufficient to meet the requirements without the necessity of changing scale factors. For example, for the purpose of low altitude visual navigation training, the inflexible scaling of the CCTV-model system is a severe disadvantage because of the conflicting requirements for high resolution and large area coverage. On the other hand, for a simulation problem such as ship-to-ship--underway replenishment involving the approach and station keeping of two large objects on an essentially flat, featureless and infinite plane (the open sea) this characteristic does not constitute a disadvantage for the CCTV system.

Resolution. This is one of the main physical parameters of any system. For the purpose of this analysis, however, the specific values are less important than the gross categorization of systems in terms of whether their resolution is representative of optical quality, photographic quality or TV quality.

Detail Requirements. This characteristic refers to the amount and type of detail which must be available in the visual scene to meet the mission requirements. It therefore defines the problems to be solved in the selection and encoding of visual information for storage. As one might expect, the importance of this characteristic varies widely depending on the image storage medium involved. For example, it is relatively unimportant in most photographically based systems, becomes a significant factor in the design of CCTV-model systems and is a critical aspect of computer-generated systems.

Color Capability. This characteristic refers to the fidelity of color reproduction of the system. For the purpose of this analysis, only gross categorization is required. Systems can be classified simply on the basis of whether they are capable of producing black and white only, partial color as in systems based on 2-color mixtures, or full color as in systems based on 3-color mixtures or optically viewed models.

Absolute Brightness. This is a basic parameter of all simulation systems. For obvious reasons, low absolute brightness is frequently a serious disadvantage of systems designed to provide extremely wide fields of view.

Contrast Range. This is a self-explanatory system characteristic. In general, however, if a system delivers adequate brightness, the contrast range will also be adequate.

Distortion Tolerance. In the context of this analysis, this characteristic refers to the perceptual acceptability of simulation imagery which has been purposely distorted by the system, as in the VAMP-type semi-closed loop movies.

Flicker Tolerance. This is a basic factor in both TV and motion picture systems. Although it does not usually present a problem, it can be a serious disadvantage in some applications of extremely wide angle motion picture systems.

Accommodation to Infinity. In the context of this analysis, this characteristic refers to the relative ease or difficulty of displaying the obtained imagery in such a way that it appears at infinity. For example, some systems lend themselves to the use of relatively compact virtual image displays, while others require that the image plane be physically remote from the viewer, therefore resulting in a large and expensive installation to achieve the same effect.

Relative Motion. This factor is concerned with the angular velocities expected on the basis of mission requirements and with their anticipated effects on various system parameters such as image smear, stroboscopic effects, and the detail requirements of the storage medium.

Independent Closed-Loop Motion. This characteristic refers to the relative ease or difficulty in providing independent closed-loop motion of targets within the simulated visual environment. For some missions such as air-to-air combat maneuvering, this capability is essential. A mission segment such as weapon delivery (including all types of missiles, fixed and flexible gunnery), which requires the provision of visual ground-effects, constitutes a special case in that the position of impact is determined by ballistic computation (i.e., the control loop is closed mechanically or electronically rather than manually). Simulation systems differ widely in their ability to provide this feature. For example, while it is possible to utilize a CCTV-model system for air combat simulation, the solution is necessarily large and complex. Computer-generated displays, however, are well suited to such problems and, in addition, can provide any type of weapons effects desired, including even tracer paths.

Coupled Motion. This factor is concerned with the feasibility of coupling a motion platform with the visual system under consideration to provide the integrated sensory cues required for vehicle control training. Mission considerations dictate both the requirement for, and the degree of, coupling. For example, for stable and slow-moving vehicles such as ships involved in harbor navigation and in docking, visual representation of the motion cues is sufficient in itself. Simulation of an assault boat landing, however, requires precise coupling of the two systems because the vehicle control task is critically dependent upon the relationship between the visual and motion cues.

Closed- vs. Open-Loop Operations. This basic parameter is determined by whether or not control actions are fed back into the system. In open-loop systems, there is no control feedback; and the resultant imagery is fixed or programed as in most vehicle control simulations or mechanically as in the simulation of weapons effects which was mentioned earlier. The critical importance of this parameter in many training situations is due to the fact that closed-loop operation demands active participation of the trainee in accomplishing the control task and provides feedback to him concerning degree of success. Special techniques are available to achieve these ends in certain types of open-loop simulation but, in general, they are more limited in their application and therefore less satisfactory.

Angle of View. This is a critical parameter in the design of simulators for many training purposes. Other things being equal, it is desirable to provide the widest angle of view achievable. Some mission requirements, however, are more stringent than others in this respect. For example, for air-to-ground weapons delivery, a wide angle of view is desirable, but not essential, since bomb, missile and fixed gunnery targets will generally be close to the flight path. On the other hand, for simulation of the low altitude navigation problem, visual information from the extreme periphery is essential and therefore, an extremely wide angle display is required.

Depth of Field. This is a basic parameter which does not usually constitute a problem for most system/mission combinations, since in most cases, the actual distance from optical probe to area of interest is sufficiently great that a normal optical system stopped down to a small aperture will yield adequate depth. A very small lens aperture, of course, creates other problems such as the necessity to either increase the illumination level or the sensitivity of the recording device. There are, however, mission specific situations in which depth of field does present a serious system limitation independent of both brightness and sensitivity, e.g., when an optical probe is required to come very close to a surface such as in a CCTV-model simulation of carrier takeoff and/or landing.

Ease of Change. This factor refers to the relative ease of making changes in the visual information which is already coded and stored in the system. It is, of course, related to, but not identical with, the scaling factor discussed earlier. While flexible scaling refers to the complete replacement of one stored visual environment by another having a different scale factor, ease of change refers to the relative simplicity of updating an existing image store by making small localized changes. This characteristic can be illustrated by comparing the photographic (factored transparency) and the computer-generated approaches to radar landmass simulation. Factored transparency systems which represent geographic and cultural features as a function of elevation in one transparency and as a function of radar reflectivity in another, cannot be updated when, for example, radar targets such as bridges, highways, dams, reservoirs, etc., are created or destroyed. It is, of course, apparent that computer-generated imagery can be updated with ease by appropriate programing changes.

Monocular Movement Parallax. This is one of several factors concerned with the cues which govern the perception of apparent depth in the imagery delivered by a system. Monocular movement parallax refers to whether or not objects in the background of a scene appear to move in relation to the foreground, as a function of relative motion between the observer and the target area. Since both the direction and velocity of this apparent motion constitute cues to the depth of an object in the real world, this factor is a powerful determiner of the corresponding illusion in the simulated environment. Generally, monocular movement parallax is based upon three-dimensional inputs, since it depends upon constantly changing aspect angles between the recording device and objects in the visual field. Although a regularly changing target aspect angle is a necessary condition for deriving the movement parallax depth cue, it is not in itself sufficient; the target aspect angles must be changing at or above some threshold value. The practical significance of these considerations is that, taken together, they define a range limitation for some missions (e.g., air-to-ground target acquisition, remotely controlled (TV) guided missiles) beyond which depth cues based on this principle will not be effective.

Interposition. This, like monocular movement parallax, is another of the basic cues to depth. However, unlike the former, the illusion of depth is not dependent upon motion, but upon the individual's learned response to certain characteristics of identifiable patterns. Through experience, an individual learns to interpret certain shapes as representative of certain classes of objects. When the expected image of a man interrupts or cuts off a portion of the image to be expected of a tree, the man is interpreted as being in front of (closer to the observer than) the tree. Provided that the geometric relationships between the relative size of known objects is preserved, within very broad limits, interposition is a simple but very powerful cue to depth. Most simulation systems which are based upon three-dimensional inputs (optical or TV-viewed scale model, movies based on either the real world or models if it) provide this cue automatically. Artificially calculated visual environments (e.g., computer-generated imagery, animated motion pictures) can also provide these cues, but at some cost in programing effort. In some cases, however (e.g., point light source - transparency systems), the inability to provide this cue is a substantial disadvantage of the system.

Physical Size. This is an obviously important aspect of any system in that it is closely related to overall cost. In the context of our analysis, only gross categorization is necessary. These categories are defined as follows: 1) small--desk-top to small classroom size, 2) medium--a space requiring special preparation such as an unusually high ceiling, a false floor, special cooling arrangements, etc., and 3) large--requiring a special building, exceptionally large room, or an unusually extensive modification of an existing building.

Power Consumption. This is another cost-related parameter which both reflects and is reflected in the size, weight, illumination and cooling requirements of the system. For the purpose of this analysis, the following categories are defined:

1) small--up to 10 KW
2) medium--10 to 50 KW
3) large--over 50 KW

Original Hardware Cost. For the purpose of this analysis the following categories are defined:

Low--up to 250K
Medium--250K to 1.5M
High--above 1.5M

Original Software Cost. For the purpose of this analysis, original software costs are classified as follows:

Low
Medium
High

Maintenance Costs. This factor includes both hardware (parts replacement and equipment repair) and software (programing) support required for adequate availability. For the purpose of this analysis maintenance costs are classified as follows:

Low
Medium
High

Some Insights About Visual System Characteristics. It is apparent that the importance to be attached to any individual system characteristic varies depending on both the mission and the simulation system involved.

While all of the 23 characteristics cited are relevant to some combination of mission segment and simulation technology, few, if any, have relevance for the entire range of such possible combinations.

A given system parameter, such as resolution (which is a quantitatively measurable aspect of any display system), is a significant characteristic only if it is substantially greater than, or less than that required on the basis of mission considerations. For example, if the available system resolution exceeds the resolution required to simulate a given operational environment, the proposed system represents a significantly "overengineered" (and therefore overpriced) solution in respect to this particular parameter. Similarly, wherever the system capability is substantially less than the requirements, the parameter in question constitutes a significant disadvantage of the system for that specific application.

While only those systems characteristics for which requirements and capabilities are for some reason unequal are to be considered significant, it is apparent that not all significant characteristics are important from the practical standpoint. This is because the nature of our primary interest necessarily emphasizes the disadvantages or shortcomings of competing technologies rather than their advantages. For example, in our context, a parameter which is identified as a system advantage for a given application usually requires no further consideration. Conversely, a characteristic identified as a system disadvantage must be further considered in terms of its criticality, i.e., a system disadvantage may be either a critical or a non-critical factor in the ultimate hardware selection process. The designation of individual system characteristics as important or critical in achieving a specified simulation goal is a judgment which requires considerable knowledge and experience on the part of the specialists involved.

These judgments constitute an important step in the overall decision process in that they identify those difficulties which must be overcome by each of the candidate technologies in order to achieve the desired objective. In terms of this analysis, a critical system deficiency for any specified application is defined as one which can be circumvented only at considerable cost to the system, in terms of money, complexity, development time, maintainability and engineering risk.

Step 4: Construct a series of matrices correlating visual simulation requirements with system characteristics

The application of this technique to an actual visual simulation problem is illustrated with an analysis of three candidate simulation technologies as a function of the same set of simulation requirements. These are: 1) CCTV, 2) open-loop movie, and 3) computer-generated simulation systems. The low altitude visual navigation problem (see Table 3) is selected because of the stringent requirements it imposes on the hardware solution with respect to several important system characteristics, viz., angle of view, scaling, resolution, depth cues, and the desirability of closed-loop operation. The analysis will result in three separate system characteristic profiles on the basis of which the relative strengths and weaknesses of each of the candidate systems may be compared.

The format adopted for the multiple decision matrices is illustrated in Figure 3. With few exceptions, which are noted below, all matrices are identical, consisting of nine cells in a 3x3 block arrangement. There is an individual matrix for each of the 23 system characteristics (e.g., scaling, resolution) previously discussed. Each of these general system characteristics is evaluated in terms of the mission-derived simulation requirements on the vertical axis, and the specific system characteristics available on the horizontal axis. Each cell of the matrix is pre-numbered with a "value" ranging from -2 to +2 (the specific digits in themselves have no quantitative significance). The primary feature of each matrix is that the digits are arranged so that a "0" score is obtained whenever, in the judgment of the specialist, the simulation requirement as determined by the nature of the mission is met by the specific characteristic of the system under consideration. Matrix cells containing negative numbers will be obtained when the judgment is made that the specific system characteristic is not adequate to meet the requirement. Similarly, a positively numbered cell indicates an unneeded or excess capability of the system in question for the purpose of achieving the defined objective. It should be noted that, since the format of the matrices is essentially uniform throughout, the specific judgments required for each of the requirement/capability combinations vary somewhat. For example, some matrices are simply labeled high, medium and low on each of the axes. In these cases, which tend to be associated with basic system parameters, the judgments to be made are, a) what level of

TYPE OF VEHICLE & GENERAL MISSION: __________
SPECIFIC MISSION SEGMENT: __________
SYSTEM TYPE __________

VISUAL SIMULATION REQUIREMENTS		SYSTEM CHARACTERISTICS		
		Primary Advantage	Secondary Advantage	Primary Disadvantage
Flexible Scaling	Required	0	-1	-2
	Desired	1	0	-1
	Not Necessary	2	1	0

		High	Medium	Low
Detail Requirement	High	0	-1	-2
	Medium	1	0	-1
	Low	2	1	0

		High	Medium	Low
Brightness	High	0	-1	-2
	Medium	1	0	-1
	Low	2	1	0

		Optical	Photo	TV
Resolution	Optical	0	-1	-2
	Photographic	1	0	-1
	TV	2	1	0

		Full	Partial	Absent
Color	Full	0	-1	-2
	Partial	1	0	-1
	Absent	2	1	0

		High	Medium	Low
Contrast Range	High	0	-1	-2
	Medium	1	0	-1
	Low	2	1	0

		Inherent Distortion		
		Low	Medium	High
Distortion (tolerance)	Low	0	-1	-2
	Medium	1	0	-1
	High	2	1	0

Figure 3. Format for the Multiple Decision Matrices (Part 1 of 3)

VISUAL SIMULATION REQUIREMENTS		SYSTEM CHARACTERISTICS		
		Primary Advantage	Secondary Advantage	Primary Disadvantage
Accommodation to Infinity	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

		Primary Advantage	Secondary Advantage	Primary Disadvantage
Independent Motion of Targets in Field	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

		Unprgmd	Semi-Prgd	Prgrmd
Control of Visual Environment	Unprogramed	0	-1	-2
	Semi-Prgmd	1	0	-1
	Programed (closed loop)	2	1	0

			Degree of Flicker	
		None	Medium	High
Flicker(tolerance)	None	0	-1	-2
	Medium	1	0	-1
	High	2	1	0

			Susceptability to Smear	
		Low	Medium	High
Relative Motion of Targets	High < Vlcty	0	-1	-2
	Medium < Vlcty	1	0	-1
	Low < Vlcty	2	1	0

			Difficulty/Expense of Providing Required Coupling	
		Low	Medium	High
Coupling of Visual Field with Real Motion	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

		Wide	Medium	Narrow
Angle of View	Wide (140° up)	0	-1	-2
	Medium (90°-140°)	1	0	-1
	Narrow (less than 90°)	2	1	0

Figure 3. Format for the Multiple Decision Matrices (Part 2 of 3)

VISUAL SIMULATION REQUIREMENTS

SYSTEM CHARACTERISTICS

		Extensive	Moderate	Small
Depth of Field	Extensive	0	-1	-2
	Moderate	1	0	-1
	Small	2	1	0

		Primary Advantage	Secondary Advantage	Primary Disadvantage
Monocular Movement Parallax	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

		High	Medium	Low
Ease of Changing Visual Environment	High	0	-1	-2
	Medium	1	0	-1
	Low	2	1	0

		Primary Advantage	Secondary Advantage	Primary Disadvantage
Interposition (Terrain Masking)	Required	0	-1	-2
	Desirable	1	0	-1
	Unnecessary	2	1	0

	Small	Medium	Large
Size of Installation	0	-1	-2

	Low	Medium	High
Original Hardware Cost	0	-1	-2

	Low	Medium	High
Maintenance Cost	0	-1	-2

	Low	Medium	High
Power Consumption	0	-1	-2

	Low	Medium	High
Original Software Cost	0	-1	-2

Figure 3. Format for the Multiple Decision Matrices (Part 3 of 3)

the specific characteristic is required on the basis of the known facts about the mission, and b) what is the gross ability of the system in question relative to the specified characteristic. In some cases, the same basic judgments are required, but for convenience, the axes are labeled in terms of the characteristic itself. Thus, angle of view, is labeled in terms of wide, medium and narrow; color, in terms of full, partial or absent.

Another type of judgment is required for such system characteristics as independent motion, flexible scaling, accommodation to infinity, monocular movement parallax and interposition. In these cases, the pertinent judgments are: a) whether the characteristic in question is required, desirable or unnecessary in order to achieve the simulation objective as defined by the mission, and b) whether the characteristic constitutes a primary advantage, a secondary advantage, or a primary disadvantage of the system under consideration.

Finally, with respect to several cost-related factors such as power consumption, maintenance costs, etc., the usual nine cell matrix is reduced to three. This is because by definition, only low cost, low maintenance, low power consumption, etc., is required (i.e., desired).

> NOTE: The steps described thus far are accomplished by the human factors specialist. Beginning with Step 5, the output reflects the combined efforts of human factors and engineering working interactively.

Step 5: Develop a system characteristic profile for each candidate engineering approach depicting the matrix scores for each visual system characteristic

The format of the system characteristic profiles derived from the multiple matrix scores is illustrated in Figure 4. The 23-system characteristics selected for analysis are arrayed along the horizontal axis and individual matrix scores are plotted vertically. When the individual points are connected, a "profile" is formed which graphically portrays the ability of the simulation system under consideration to meet the simulation requirements of the selected mission. A given profile is concerned with the "fit" of only one system/mission combination; successive analyses are made for each of several candidate systems in order to provide a basis for comparing alternative engineering solutions. The development of the profiles is accomplished by human factors and engineering specialists in consort to insure that competitive technologies are most systematically and logically evaluated. This is an important requirement since the precise definition of all the visual cues necessary to meet the training requirement for a given mission is often such a difficult, and time-consuming task that it constitutes a major disadvantage of the approach in itself.

TYPE OF VEHICLE & GENERAL MISSION: ______________________

SPECIFIC MISSION SEGMENT: ______________________

EVALUATOR(S): ______________________

SIMULATION SYSTEM: ______________________

CRITICAL FACTORS	MATRIX SCORE			
	-2	-1	0	+1 +2
Scaling (3)				
Resolution				
Detail Required				
Color				
Absolute Brightness				
Contrast Range				
Distortion Tolerance				
Flicker Tolerance				
Accomodation to Infinity				
Relative Motion				
Independent Motion				
Coupled Motion				
Programmed/Unprogrammed(2)				
Angle of View (1)				
Depth Of Field				
Ease of Change				
MonocularMovement Parallax				
Interpositioning				
Physical Size				
Power Consumption				
Original Hardware Cost				
Original Software Cost				
Maintenance Cost				

Figure 4. Format of System Characteristics Profile

The results of the matrix analyses of the three candidate simulation systems with respect to the simulation requirements of the low altitude visual navigation mission are summarized next. For the low altitude visual navigation problem three system characteristics were designated as critical factors. These are, in the order of their presumed importance, angle of view, programed vs. unprogramed, and scaling.

In order to fully understand the derivation and use of the information presented in the matrix profiles, it is first necessary to understand the visual simulation requirements of the low altitude, visual navigation mission. The simulation requirements of this mission indicate that:

a. An extremely wide angle of view is essential since many of the visual cues necessary for proper geographic orientation at low altitude are derived from the peripheral field.

b. An unprogramed (closed-loop) capability is highly desirable since the trainee must be able to exercise active control of his flight path. Whether or not this feature is essential (as opposed to desirable) is a matter of interpretation. It can be argued that since the navigation problem involves only minor deviations from a prescribed path down a defined series of terrain corridors, only a semi-programed capability is required.

c. Some form of flexible scaling is essential because the nature of the low altitude navigation mission requires large area coverage at fairly high resolution.

d. The ability to provide adequate depth cues is essential because the shallow look down angles, relatively short slant ranges, and high angular velocities characteristic of low altitude flight produce many operationally important cues which are based on interposition and on monocular movement parallax (e.g., target/terrain masking-unmasking). In this particular analysis, however, neither monocular movement parallax nor interposition were designated as critical factors because all three candidate systems are capable of meeting the requirement. Thus, although these characteristics are essential to a successful simulation of the low altitude navigation mission, it would serve no purpose to designate them as critical factors since they would not differentiate between possible engineering solutions.

In addition to the above, it should be noted that the requirement for visual information in the extreme peripheral field has implications for several other system characteristics. Thus, in an extremely wide angle display, the absolute brightness, flicker tolerance, accommodation to infinity and relative motion characteristics take on added importance and, in fact, can become critical.

Figures 5, 6 and 7 depict system characteristics profiles for the three candidate simulation systems. A comparison of the three profiles reveals that for the simulation of the low altitude visual navigation mission:

a. The CCTV-model system has two major disadvantages, viz., narrow angle of view and difficult scaling problems. In addition, it requires a relatively large and costly installation. The primary advantage of this type of approach is in its ability to provide unprogramed, or closed-loop operation. The profile also shows that resolution is marginal and there is an appreciable susceptibility to image smear. On the other hand, color, brightness, contrast, distortion, depth cues and original costs are considered adequate.

b. The wide angle open-loop movie system has (as its name implies) one major disadvantage, open-loop operation, and one major advantage, the ability to provide extremely wide angle imagery. Flexible scaling which presents a major problem for the CCTV-based system is an inherent property of the motion picture-based system. Resolution, color, distortion and depth cues were all judged to be adequate. There are, however, some problems with stroboscopic effects and image smear in the extreme periphery. Size, hardware and maintenance costs are more or less moderate, but the cost of acquiring properly controlled imagery (software) is high. It should be noted here that care must be exercised in the interpretation of any matrix score shown on a profile, since any given score is the result of the interaction of simulation requirements with system characteristics. Thus, in Figure 5, both the independent motion characteristic and the ease of change characteristic are plotted as "0's," meaning that the simulation requirement is met by the specific system characteristic in question. This is in fact true for both cases. However, the key to the effective use of this information is in the mission-derived simulation requirements. For example (refer to Figure 3), independent motion of targets within the visual field is not considered a necessary feature of the low altitude visual navigation problem. Even though the inability of the open-loop movie system to provide such motion is a primary disadvantage of the system per se, it does not constitute a disadvantage in achieving the simulation objectives of this mission. Similarly, because the ability to make small localized changes in the stored imagery is not required in this case, there is no discrepancy between the simulation requirements and system capability concerning the ease of change characteristic.

c. The computer-based imagery system is certainly the most flexible and therefore potentially the most useful of all the simulation technologies. However, its extreme flexibility is both its greatest strength and its greatest weakness. As mentioned previously, one of the greatest advantages of computer-generated imagery is that the available resolution elements ("edges" or "lines" depending on the specific technique involved)

TYPE OF VEHICLE & GENERAL MISSION: Fixed-Wing - Air-to-Ground

SPECIFIC MISSION SEGMENT: Low Altitude Visual Navigation

EVALUATOR(S): Human Factors Specialist

SIMULATION SYSTEM: CCTV-Model

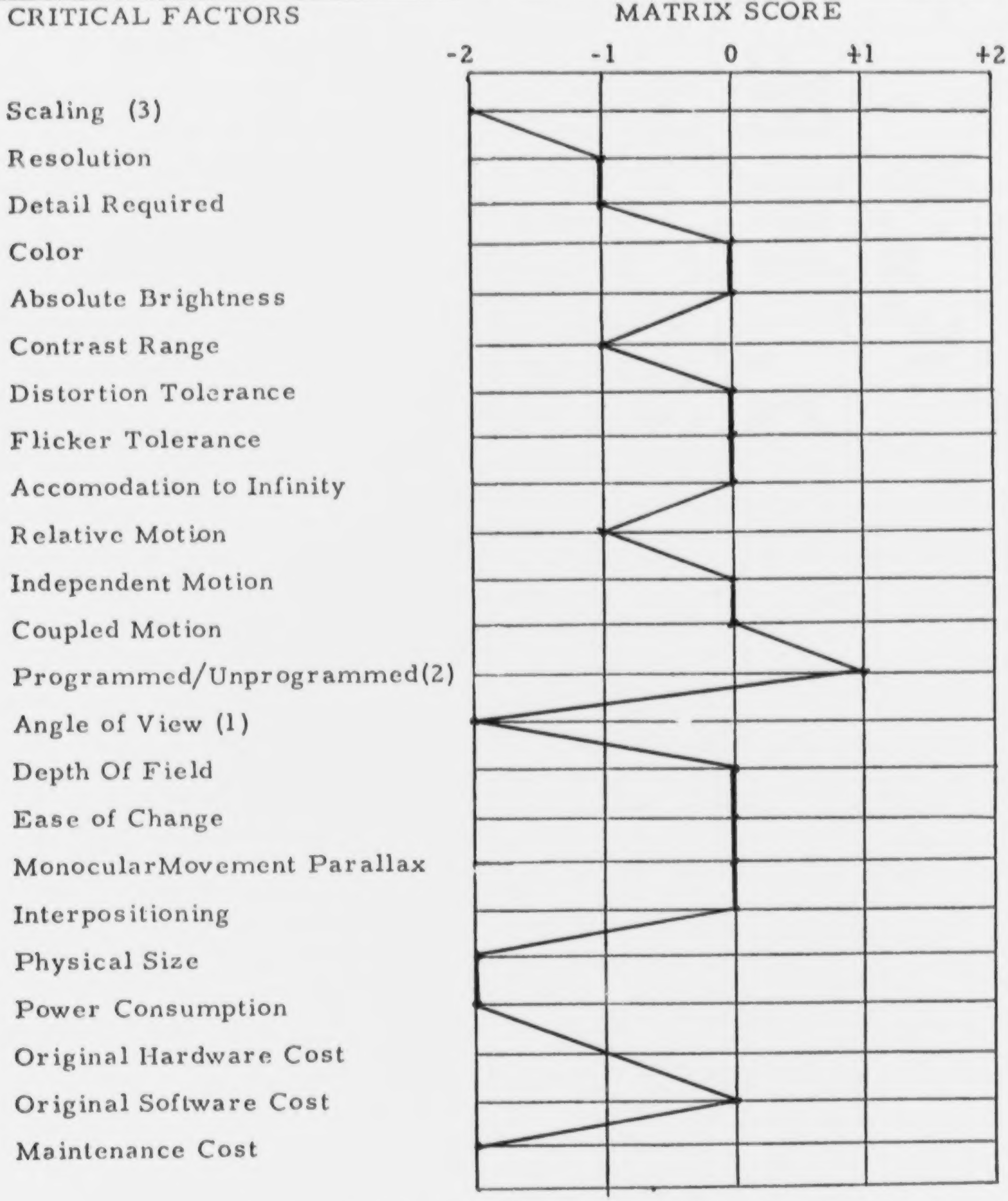

Figure 5. System Characteristics Profile for the CCTV-Model Simulation System.

TYPE OF VEHICLE & GENERAL MISSION: Fixed Wing - Air to Ground

SPECIFIC MISSION SEGMENT: Low Altitude Visual Navigation

EVALUATOR(S): Human Factors Specialist

SIMULATION SYSTEM: Open Loop Movie

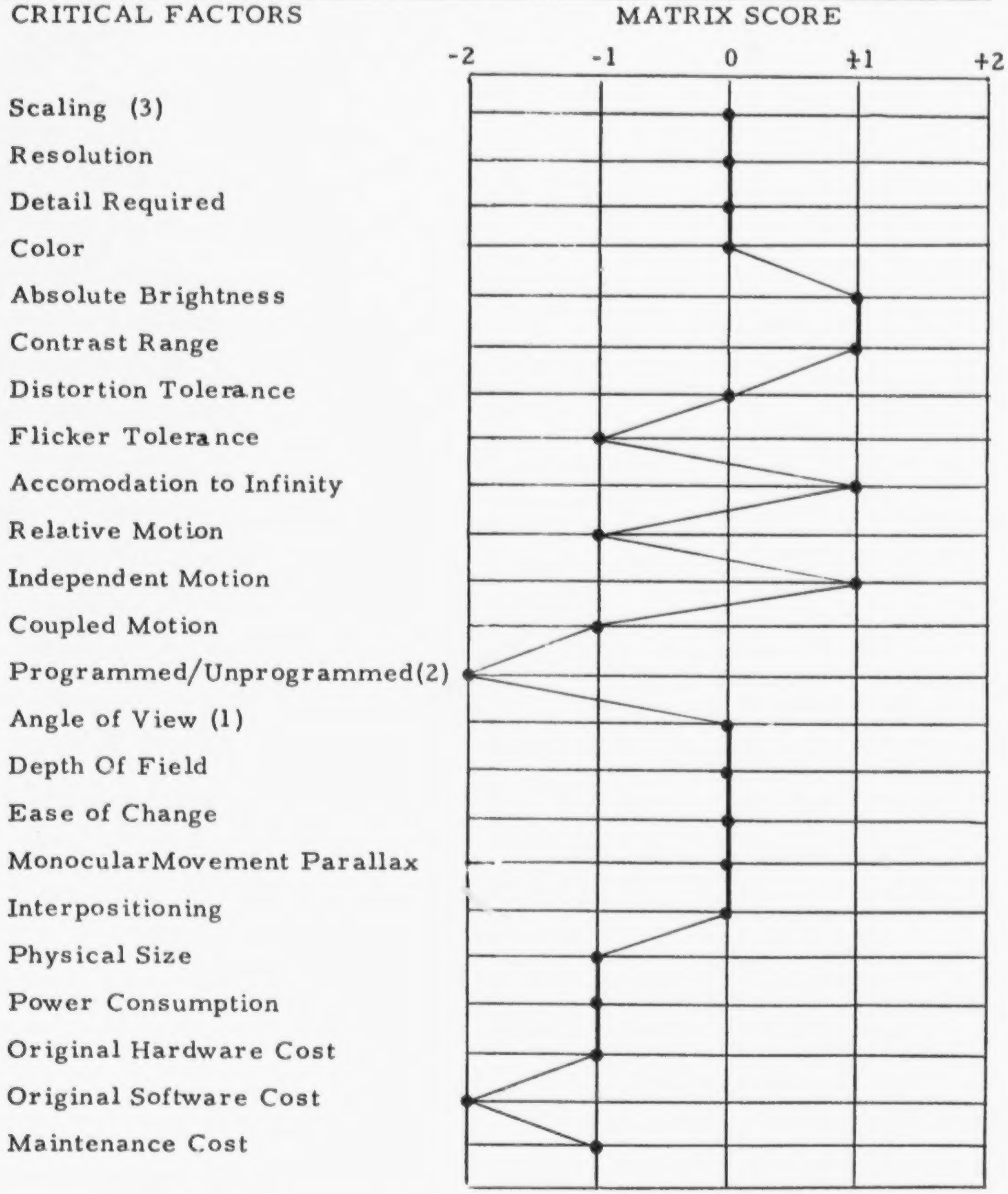

Figure 6. System Characteristic Profile for the Open Loop Movie Simulation System.

TYPE OF VEHICLE & GENERAL MISSION: Fixed Wing, Air to Ground

SPECIFIC MISSION SEGMENT: Low Altitude Visual Navigation

EVALUATOR(S): Human Factors Specialist

SIMULATION SYSTEM: Computer Generated

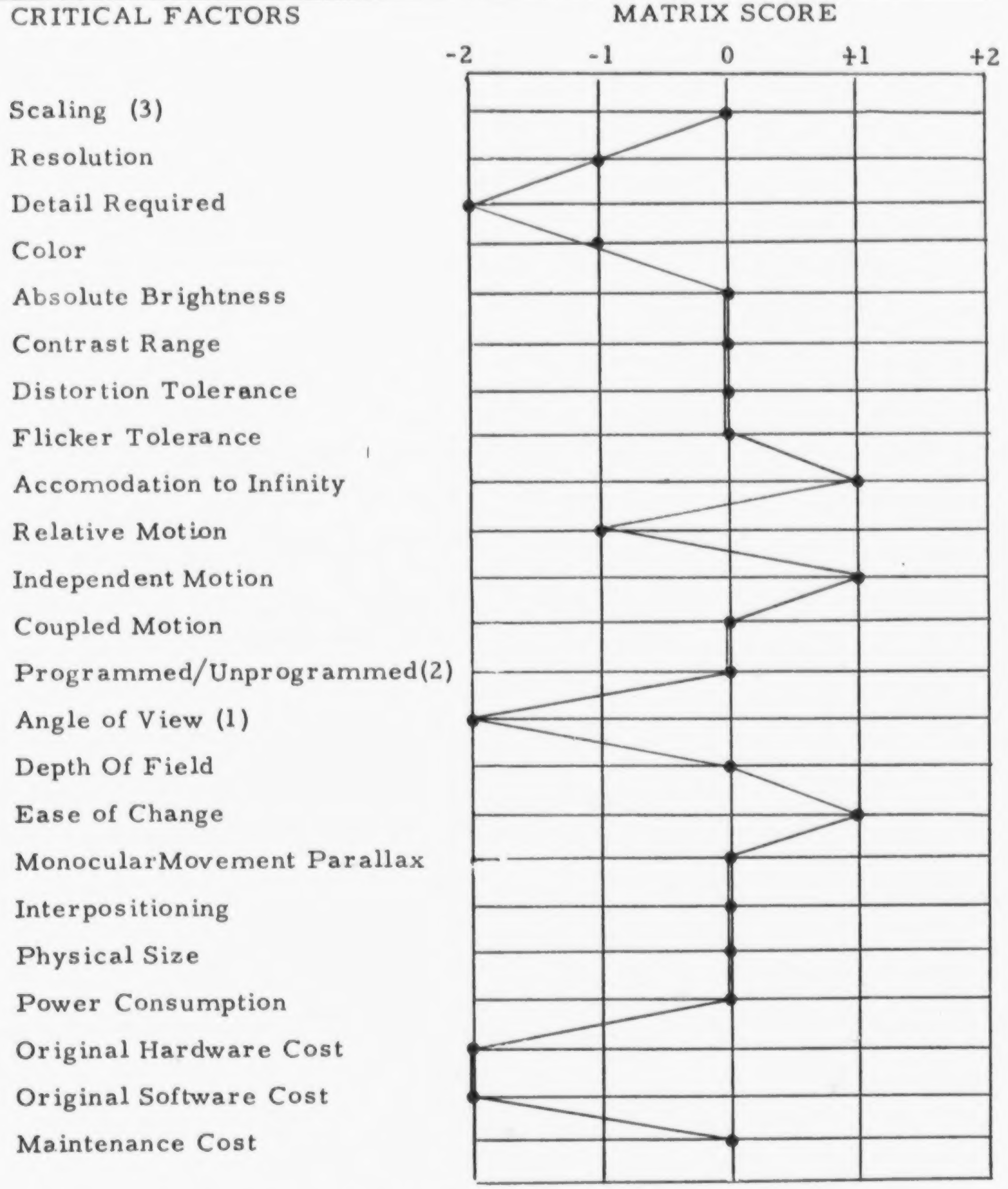

Figure 7. System Characteristics Profile for the Computer Generated Simulation System

can be differentially apportioned according to the areas of interest in the visual scene. For example, in an air-to-air combat simulator, most of the available resolution elements could be devoted to defining the image of other aircraft in the visual field at the expense of ground detail, which is only needed for gross orientation. While this capability is a distinct advantage of the computed image technique, implementing it presents a major problem. This is directly expressed in the detail requirement characteristic, and indirectly reflected in the high software cost factor. Of the system characteristics which were previously designated as critical factors, the computer-generated technique is deficient in only one, i.e., angle of view. However, the highly negative detail requirement factor should be regarded as a special disadvantage of this technique because of its influence on the values of the closely related scaling, resolution, color, depth and cost factors. Obviously, in any system based on the manipulation of a mathematically defined visual environment each element of that environment must be carefully preselected and incorporated with all of its arbitrarily assigned parameters (such as color) into the mathematical model.

Beyond the profile analysis, it is recommended that the team develop a quantified figure-of-merit for each candidate engineering solution for meeting the design requirements. This requires that careful thought be given to differentially weighting the characteristics in the profile (with an identification of the critical requirements which must be satisfied). An attempt to quantify (via FOMs) serves two purposes: it enables greater precision in arguing the relative merits of candidate approaches; and contributes towards improvements in the technique by the "forced" development of empirical weightings which, with experience, may eventually be established for each system characteristic.

Summary

The analytic technique described here provides a means for organizing, displaying, and evaluating the technical information which is already available concerning the interaction of visual simulation requirements and techniques. While the basic approach employed is imperfect, it is believed to be sound and logically defensible and worthy of refinement by practical use. Figure 8 summarizes the series of steps accomplished in the procedure.

2.3.3 CASE 3: Technique for Defining Display and Control Requirements in Generalized Trainee Station Design

There are instances where the purpose of training is best achieved via a generalized training device (either single station or multiple but independent stations). In this situation, device design is general to a variety of vehicles, but not identical in layout, dimensions, equipment, etc., to any existing vehicle; in addition, an array of displays and controls provides

Steps

Step 1	Step 2	Step 3	Step 4	Step 5
Identify the visual simulation problem	Identify the candidate engineering approaches for solving the visual simulation problem	Describe the visual system characteristics which bear on the hardware selection process	Construct matrices correlating visual simulation requirements with system characteristics	Develop a system characteristic profile for each candidate engineering approach depicting the matrix score for each visual system characteristic

Outputs

Step 1	Step 2	Step 3	Step 4	Step 5
Characteristics of the operational environment to be simulated	Relevant design options and the relative advantages and disadvantages of each	Description of the pertinent visual system characteristics	Correlation of the design option capabilities with training requirements (mission simulation requirements vs. design option characteristics)	Quantified figure-of-merit based on weighted total score for all system characteristics per candidate engineering approach

Figure 8. Procedure for Comparing Alternative Engineering Solutions to Achieve Simulation Requirements.

only that information needed by the student to perform the functions of the job. The selection of the instruments needed to provide these vital functions and the kinds and amounts of information displayed are the issues of concern. Implicit in this situation is a substantial simplification in representation while maintaining behavioral similarities between the device and the operational system jobs. An emphasis is placed on simulating the stimuli and responses found in the operational situation. The human factors effort is to specify the information requirements needed for this type of training wherein the content is relevant to a variety of operational situations. The design rationale is to provide only those functions needed in job performance. This involves the installation of a task environment which affords the student the opportunity to learn and retain skills which are common to a number of systems.

A technique is provided here for deriving information requirements for situations calling for generalized displays and controls wherein 1) the stimuli and responses of the operational environment are simulated (i.e., behavioral similarities between the device and the operational counterpart functions), and 2) simplification in the degree of fidelity of representation is achieved commensurate with the generalized functions provided. In this case, the content deals only with the design requirements for the displays and the associated controls for enhancing the instructional process. That there are other human factors requirements involved with training devices of this type is tacitly assumed.

The procedure outlined below utilizes Device 1D23 as the model for the analysis[1]. Device 1D23 is a multi-station Air Navigation Trainer (forty independent cockpits, six instructor stations) which simulates characteristic navigator functions generalizable to a variety of aircraft types although the cockpits are not identical to any given aircraft. The purpose of the trainer is to instruct Naval Flight Officers in basic air navigation and communication procedures and concepts. The device characteristics include:

- preprogramed lesson plans with enroute modification capability
- computer-controlled cockpit environment
- automated measurement capability

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[1] The analytical derivations are based on two sources: 1) Specification for Trainer, Communication and Navigation, Device 1D23, 313-1115, Task 1309, U.S. Naval Training Device Center, Orlando, Florida, 5 January 1971, and 2) Bark, M., et al, Design Study Report for a Multiple Trainer Station Air Navigation Trainer, NAVTRADEVCEN 68-C-0308-1, U.S. Naval Training Device Center, Orlando, Florida, January 1969.

- instructional assists in the cockpit (annunciator panel, performance status indications, knowledge of performance and cueing information)

- communications between student and instructor/operator

- student flight command controls

- student response controls to respond to instructor or to computer interrogations.

In this case example, the emphasis is placed on deriving information requirements relative to the design of generalized displays and controls for a training device. It should be made explicit that no consideration is given here to other legitimate concerns that must be accounted for in trainer development such as actual design of instruments, cockpit panel layouts, communication networks, response keyboard design as well as other human factors items in the technical approach documentation. The procedure is concerned only with deriving the stimulus and response capabilities necessary for the student to learn the generalized navigation functions, and centers on: the stimulus requirements for operational instruments; the display and control of specific stimuli, and the command and response capability provided the student. The issues to consider in assembling the information requirements pertinent to engineering design are outlined next.

2.3.3.1 Operational Instruments. The major group of instruments are those associated with the direction and movement of the aircraft in flight. These instruments provide the specific stimuli for the learned navigation responses and are of most concern in station design. The approach to deriving the information requirements that must be represented in this instrumentation should consider the following.

a. Provide the student only that information needed to effectively perform navigation problems (in a form compatible with processing requirements). The content of instruction for the navigation tasks involves:

- basic dead-reckoning navigation
- basic airways navigation
- fuel management
- relative motion training

b. From an examination of each of the content tasks, the instruments necessary to perform navigation functions are identified.

c. From this analysis, a listing of instrument stimuli is derived. Displays, indicators, and panels are to be utilized in a computer-controlled cockpit environment, hence many of the standard operational instruments are inapplicable or impractical. The displays and indicators selected for simulation are primarily those associated with navigation problem solutions. Additionally, a limited number of supporting instruments will give the student aircraft attitude and rate information. The following requirements were derived for instrument displays.

Instruments Required for Navigation Problem Solutions:

Indicated Airspeed
Mach No.
Altimeter
Magnetic Compass
Radar Altimeter
Bearing Distance Heading Indicator (BDHI)
Eight Day Clock
Outside Air Temperature
Fuel Flow Gage
Fuel Quantity Gage

Instruments Depicting Attitude or Motion, Requiring No Dependency for Navigation Problem Solution:

Gyro Horizon or Attitude Gyro
Rate of Climb

Communication and Navigation Displays and Controls:

Communication Navigation Display Panel
Communication Navigation Control Panel
Navigation Control Panel
Navigation Display Panel
MA-1 Compass Control Panel

d. Actual aircraft instruments will not be employed. Digital displays are desired for all instruments relevant to the navigational problem. Lighted numeric readouts feature faster response, higher stability and finer resolution and accuracy than the needle type display (also, the computer interface to lighted numeric readouts requires the simplest logic of any simulation technique).

e. The specific information to be displayed on each selected instrument must be defined.

f. To display rate or relative position information, hybrid instrumentation is advisable (combined digital and analog techniques). The following instrument components are simulated by the use of rate servos:

- gyro heading card (Bearing Distance Heading Indicator)
- ADF needle (BDHI)
- TACAN/VOR needle (BDHI)
- Magnetic heading card (wet compass)
- Pitch and roll (gyro horizon)

g. The response characteristics of each instrument must be determined. A simple approach for achieving this is to evaluate response across a range of update rates. In our example, two types of instrument responses were evaluated based on update rates ranging from twice per second to once per four seconds, presented to subjects who rated the "comfortableness" of the movements for each rate. Based on this concensus, an update rate of once per second was recommended for both digital movements and for needle movements.

h. A functional layout scheme must be formulated for each of the instruments selected for use in the cockpits, based on importance and frequency of usage. In the 1D23 instance, estimates were made by subject-matter experts on the importance of the instruments in navigation. Each instrument was rated on a scale of 1 to 10 in terms of increasing criticality or importance to navigation. The average ratings were as follows:

Instrument	Rating
1) BDHI	1.2
2) Radar (Blank)	1.4
3) Indicated Airspeed & Mach No.	1.8
4) Pressure Altimeter	2.0
5) CNI Panel	3.2
6) Navigation Display • Doppler NAV • TAS	3.0
7) Radar Altimeter	3.8
8) Fuel Flow	4.1
9) Fuel Quantity	4.6
10) Outside Air Temp	5.2
11) Gyro Horizon	5.6
12) Rate of Climb	5.4
13) 8-Day Clock	5.6
14) Mag Compass	5.0

2.3.3.2 Specific Stimuli Presentation. Specific stimuli associated with critical and complex sequences of performance are not easily identified. This presents problems for instructional control in complex system operations, particularly in multi-station trainers where instructor personnel are not able to monitor individual performances continuously and must necessarily time-share among students in the development of instructional strategies. Thus, specific stimulus inputs requiring observable student performance in the presence of the stimulus are desirable as an assist to instructional control (behavior modification). An annunciator panel was recommended for Device 1D23 as a means for providing this precise stimulus control. This type of display presents questions at programed times which call for specific behaviors by the student. The response to these specific stimuli is monitored by the instructor on a CRT. A series of short programed questions are individually presented, requesting certain information from the student. Each question is programed to be visually displayed at specified times in the mission cycle and remains "on" for at least 30 seconds during which latency of response is recorded up to 2 minutes. Failure of the student to respond (via keyboard entry) to the question within the programed limit is recorded as an incorrect response. In all cases, information feedback is given to the student, via the computer, immediately upon completion of response to each message. A record of these transactions is stored in mass memory for post-mission critique. Potential annunciator questions, developed in conjunction with the lesson plans include the following:

- CALC ETA to Next Fly-To Point
- CALC Bingo Fuel
- CALC Bingo Time
- CALC TB to Point ZULU
- CALC MB to Next Fly-To Point
- CALC WS
- DME TACAN Theta
- CALC TAS
- CALC Pres. Posn.
- CALC Dens. Alt.
- CALC MH
- CALC True GS
- CALC Intercept Time

Each message, containing a maximum of 30 characters, will be used to determine the student's knowledge during inflight procedures. The trainee station computer will monitor and store both the question and response, providing a recorded means for critiqueing performance. The student responses to the annunciator questions are entered via the keyboard which provides the response options shown in Table 5.

2.3.3.3 Command and Response Capability. Means must be provided the student for giving commands to the "pilot" (vehicle control) and for responding to instructional interrogation. All inputs for pilot commands and for instructional responses are entered and transmitted by keyboard

TABLE 5. TRAINEE RESPONSE PUSHBUTTON FUNCTIONS

No.	Pushbutton	Function	Units
1.	Time - Hr/Min	Calculated Time	Hours/minutes
2.	Speed - Knots	Calculated Airspeeds or Ground Speed	Knots
3.	Bearing/Heading	Calculated Bearing or Heading	0-360°
4.	Fuel - lbs/pph	Calculated Fuel Quantities or Fuel Flow	pounds or pounds per hours
5.	Distance - N. M.	Calculated Distances	Nautical miles
6.	Altitude - Feet	Calculated Altitudes	Feet
7.	Latitude - Deg/Min	Calculated Latitude	Degrees/minutes
8.	Longitude - Deg/Min	Calculated Longitude	Degrees/minutes

and monitored each half-second by the trainee station computer. Since no pilot is involved in the navigation problem, the student recommends flight regimes to the computer by selecting one of eight available options, shown in Table 6. The command and response equipment also provides performance information to the student. A status indicator displays the results of the student responses. When an answer is correct or in-tolerance, the word, "correct," is illuminated; when an answer is incorrect or out-of-tolerance, the word, "incorrect," is illuminated together with a two-digit display indicating extent of error.

Stimulus support is available to the student via a position request, control and indicator. The student is afforded the option of requesting position information (latitude and longitude) when he suspects that his calculations are in error or that he is lost.

2.3.4 CASE 4: Employing Training Technology to Enhance Training

The cases provided thus far have been concerned with the information requirements relative to variations in fidelity on the engineering continuum. Several levels of fidelity are appropriate in installing the required instructional environment in the trainee station. High fidelity physical correspondence to the operational environment is desired in situations demanding direct transfer of training from the device to the operational system, particularly in advanced instruction and in training involving emergency conditions. Deliberately backing off from duplicating the characteristics of the operational situation (e.g., reductions in engineering tolerances, generalized training devices, part-task trainers, procedures/familiarization trainers, etc.) is also a prevalent design option. The salient feature here is the cost economy achievable due to reductions in engineering fidelity without compromising training effectiveness. In design areas where the engineering state-of-the-art is less than adequate, considerable attention must be devoted to insuring that the unintentional reductions in tolerances are the best achievable. Instructional advantage is forfeited when the resultant attenuations in fidelity are not perceived as valid by the student.

Case 4 exemplifies still another approach to simulation fidelity in trainee station design, involving planned deviations in configuration or function associated with the operational system counterpart. This differs from a cost-effective lowering of the engineering fidelity or a reduction in fidelity tolerances where the engineering state-of-the-art is less than adequate. Here the concern is primarily for the training process and includes a number of instructional assists for the student as well as the capability for student-controlled instruction (i.e., self-initiated and to a degree, self-paced). Underlying this approach is the utilization of the computer as an instructional instrument, specifically involving preprogramed training

TABLE 6. PILOT COMMAND ENTRIES BY TRAINEE

Pushbutton	Function	Units
Heading	Ordered Aircraft Magnetic Heading	0-360° Magnetic Resolution 1°
Airspeed	Ordered Aircraft Indicated Airspeed	0-400 Knots Resolution 1 knot
Altitude	Ordered Aircraft Indicated Altitude	0-65,000 MSL Resolution 1 ft.
Engine Start	Ordered Aircraft Engine(s) Start	
Taxi	Ordered Aircraft Taxi Sequence	
Commence Flight	Ordered Aircraft Flight Commencement	
Land	Ordered Aircraft Landing Sequence	
Stop Engine	Ordered Aircraft Engine(s) Shutdown	

exercises, automated performance measurement, storage of performance information, provision for knowledge of results, and the control of information presentation to the student.

A variety of design options, which are best described as deliberate departures from operational realism, are available. The intelligent use of these options (i.e., integrating the training process with engineering fidelity) serves to enhance training effectiveness by providing conditions for learning to occur; these instructional assists are also a prime means of motivating students to perform. The information requirements relative to engineering design and the instructional merit provided by these capabilities are catalogued below so that decisions about the relevance of an item to a proposed technical approach may be more systematically evaluated.

2.3.4.1 Display Enhancement. Use may be made of techniques which yield identifiable coding dimensions for enhancing the display of information to the student. Signal enhancement involves the modification of one or more of the stimulus dimensions defining the object(s) of interest in a display. The concern is for augmenting the identifiable coding dimensions by which information can best be displayed to achieve the training objectives as a function of the stage of instruction. Two types of instructional benefits accrue: 1) the probability is increased that the student will detect and classify events in cluttered displays as well as monitor signals effectively in complex displays (conspicuity and meaningfulness of signals); 2) guidance is provided to delimit the frequency and severity of incorrect responses in performance. Proper use dictates that display enhancement be under instructor control so that it may be invoked during initial training with the response cues eventually withdrawn as training progresses until the student responds to the stimulus situation which describes terminal performance.

The common techniques comprising this form of coding are the following:

- color--a practical limit is seven colors; a limit of four is desirable to alleviate color registration problems
- shape--shape coding is constrained by the ability to generate characters
- size--four size levels are recommended as a maximum limit
- intensity--this is not desirable as a coding option except as a means of attention-getting. Brightness contrast between an object and its background has limited application

- orientation--use of vectors, for example, is desirable for indicating heading, with vector length depicting speed
- pulsing--pulsing signals may indicate action required and target traces may indicate previous position
- alphanumeric -- this offers unlimited possibilities and easily interpreted meanings can be assigned

Selection of a specific technique must be made in the light of the display medium employed. CRT displays are most amenable to these techniques. Some form of temporal variation is preferred to steady state codes but for practical purposes they are equally effective in attention-getting power and in classifying multi-event situations.

Display enhancement is appropriate as a means of stimulus support during initial training where the student is required to discriminate among information classes preparatory to action. It is particularly amenable to computer-generated synthetic displays as a means of bringing the student's attention to an object or to an out-of-tolerance condition (e.g., violation of minimum lateral separation of aircraft, critical weapon release distance) which demands an immediate and appropriate response.

2.3.4.2 Performance Information Feedback. Techniques are available for providing information to the student about how the results of his performance conform to expectations or norms. Of concern is the provision for augmented information feedback, via equipment, wherein the student is provided a signal during or immediately after responding which indicates the adequacy, correctness or accuracy of his performance. This information is not in the learning task per se. This form of knowledge of results strengthens and sustains performance and aids in eliminating established but inappropriate responses. It is of particular value in indicating error to the student, for example, when error has exceeded criterion limits, when a procedural error has occurred, or when the trend of performance is approaching an out-of-tolerance condition. The salutary effects of information feedback on learning and on performance, given immediately as accrued, are will known and the use of this capability in design is highly recommended.

A number of design options is available for providing supplementary or augmented information feedback via training equipment. These involve computer control of the information feedback based on an automated monitoring, evaluation and scoring system which provides the signals for defining and selecting the message requirements as a function of student error in relation to preset tolerances. Selection may be made from among the following.

2.3.4.2.1 Error Indications on Primary Displays--This technique is applicable in situations where the student utilizes electronic displays in job performance. For example, in EW training, errors committed by the student in emitter signal analysis can be shown on the display as accrued. Most suitable is the alpha-numeric message, providing only essential information so as not to clutter the primary display (e.g., an indication of equipment locus and type of error made). Variations on this theme include the use of the following to indicate actual vs. desired values.

- pointers--panel instruments may be modified to provide visual feedback. For example, a pointer-type instrument could have a redundant pointer added. This feedback pointer would be smaller in width and length and of a different color to eliminate ambiguity.

- instrument indicator lights--this approach utilizes miniature lights built into an instrument face. When an error envelop is exceeded the lights are energized sequentially, showing a motion in the direction of the required action.

- symbolic-- feedback may be provided in the form of schematic representations of pertinent parameters such as found in Head-up displays (HUD). A variation of this for the HUD is to generate terse messages on a combining glass placed in the normal out-of-the-window field of view.

- instrument drivers-- this requires the activation of an instrument associated with the parameter requiring correction (e.g., altimeter for altitude error; the HDI for pitch or roll error). A function can be developed to drive the relevant indicator during feedback cycles, i.e., driving the instrument from the actual value to the desired value on a cyclic basis.

- peripheral indications--error readouts (indicator lights, digital readouts) may be positioned adjacent to the primary display in formats most meaningful to the remediation required (e.g., the display of adaptive training scores).

2.3.4.2.2 Auditory Signals--It is desirable also to alert the student, via audio signals, to indicate an out-of-tolerance condition at a given time. The design options include, alerting sounds and prerecorded messages.

- alerting sounds--this approach uses an audio frequency as the information feedback. The performance evaluation program, based on student response, selects an audio frequency band corresponding to the parameter out-of-tolerance. The deviation of the student's response from the desired response is proportional to the change in audio frequency from the center frequency of the selected frequency band. For example, in the flight simulator, when the pitch angle exceeds tolerances, the performance evaluation program determines that pitch angle is in error and selects the frequency band corresponding to pitch angle being in error.

- prerecorded messages--several forms are viable. In one approach, the sequence of words/syllables to compose the required message is stored digitally in computer core, disk, or drum. All possible messages are stored in memory, and the proficiency measurement programs will identify the required message, specifying the message number, code or address. the system will decode the number and thereby determine the word sequence and output the correct sequence. Audio insetting is useful when only a small number of standard formats are required for the total message. The standard formats are stored on some continuous type of audio medium (tape, cartridge, etc.). The key words describing the parameter of interest and the direction of deviation are inserted in the appropriate position. Continuous messages can be selected. In this approach, each feedback message is stored as an addressable item, and for each feedback message desired, a storage slot is required.

- computer-generated sounds based on voice synthesis--this approach requires the storage of phonetic sounds and a message is composed by the sequencing of the correct sounds. Each message stored contains the sequence of sounds and the spacing to construct messages.

2.3.4.3 Guidance Supports. Cues and prompts provided by equipment (i.e., information given prior to performing) are particularly useful during initial learning by emphasizing the relevant aspects of performance, and by limiting the exploration time and minimizing gross errors in performance. Generally, this provision of subsidiary information is more appropriate to part-task training devices than to complex weapon system trainers which place a premium on engineering fidelity and on the direct transfer of training from the device to the operational system. Pertinent guidance techniques are indicated in the following.

2.3.4.3.1 Demonstration--This capability enables the device to exhibit proper or desired performance of selected system behavior patterns, maneuvers, or emergency procedures. An enactment of some portion of the training is provided to show a desired solution, an example of a relevant event, or the actual execution of a maneuver (idealized of "school solution"). Such computer-controlled demonstrations (student or instructor initiated) provide examples of the necessary technical aspects to insure student understanding prior to his actual performance. A prerecorded verbal explanation and commentary may accompany the demonstration to enhance the instructional quality. In flight simulators, a demonstration can be executed such that cockpit instruments and the motion module exhibit movements as desired for the maneuver or flight segment selected. This may be in real time or slow time or combinations of both.

Similarly, instructional advantage is obtained by the demonstration of electromagnetic signal specifications in various EW mission contexts. The student gains an understanding of the job requirements from examples of signal signatures across the range of emitter types under the variety of reception conditions in the EW environment.

The helicopter instrument trainer, device 2B24[1] provides a number of demonstration flight segments which emphasizes instructional quality as well as technical accuracy. Examples of types of demonstration programs (provided in both real and slow time) are listed below.

- interpretation of attitude and flight control instruments; navigation instruments.
- various approaches including reporting procedures and execution of a missed approach.
  - VOR
  - tactical ADF
  - standard ADF
  - ILS
- aircraft control during climbs, descents, turns and level flight by reference to attitude instruments.
- holding at an intersection, including entry from 90°, off-axis and departure at a predetermined time.

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[1] NTDC, Specification for Synthetic Flight Training System, Device 2B24. RFP N6 1339-69-0044, Proj. 1955, Orlando Florida, 1968.

- inflight engine failure and air restart.
- instrument takeoff.

Providing the demonstration capability requires a consideration of the following:

- the aspects of the mission (maneuvers, segments, lesson plans) to demonstrate.
- the number of, and the length of each demonstration.
- the points in the mission cycle or lesson where demonstration is available.
- the means for switching from one demonstration to another.
- the initiation of, and control of, the demonstration speed (real time, slow time)

2.3.4.3.2 Predictor Instruments--This design technique involves an information display which presents future or predicted information based on manual control performance of the moment. The feasibility of this approach has been demonstrated in a number of research studies of tracking skills (see Smode 1971). An example of this is a predictor display which provides an indication of the response characteristic of a system in terms of predicted system output at some time in the immediate future. Providing the student information relative to the future of the variable being controlled simplifies considerably the continuous control task and thus provides instructional support during initial learning. The rationale for this option is the same as that indicated for display enhancement.

2.3.4.4 Trainer-Peculiar Equipments. Trainer-peculiar or extra-mission equipments refer to hardware and associates training functions which are not present in the operator stations in the actual system. Their purpose is twofold: 1) to increase training flexibility by providing the student the opportunity to select and initiate certain instructional alternatives as well as allow self-paced instruction consistent with the mission requirements and the level of training; and 2) to enhance learning through the provision of supplemental performance information not available on the job. This facet of instructional control provides an assist to the student for optimally achieving the training objectives in a sequence of instruction. The utilization of these assists is most efficient when under instructor control in a planned strategy of instruction for the individual student. Items of equipment which emphasize the "training tool" characteristics of simulation are described below.

2.3.4.4.1 Specific Stimulus Control. In complex training environments, stimuli associated with various sequences of performance are not easily identified. This hampers the control of the instructional process since the instructor is not able to correlate specific stimuli and behaviors. This problem is acute in training devices employing large instructor-to-student ratios, particularly when several stimulus inputs are combined in the performance. Means are available for presenting and monitoring specific stimuli crucial to defined performances. Specific preprogramed stimulus questions may be displayed at selected times to the student which require a defined behavior or output. The response is monitored by the instructor who usually will have available several action alternatives relative to developing an instructional strategy for the student. In training devices employing automated monitoring and scoring, with programed error tolerances for defined performances, the instructor is also able to probe for causes of violations (excessive error) by selecting and presenting pertinent stimulus questions to which the student must respond. An example of this form of stimulus control is utilized in the Air Navigation Trainer, Device 1D23 (described in paragraph 2.3.3.2). An annunciator panel displays preprogramed questions, cues or probes, and a performance status indicator provides immediate knowledge of results of how the performance requested conforms to expectations.

The design for specific stimulus control is based on the following information requirements.

- specific critical stimulus questions, cues, probes
- number of questions, cues, probes to be employed
- length and format of each stimulus item
- places in the preprogramed exercise the stimuli are presented
- time length for the display of each message
- design of the stimulus display (panel)
- form of, and the display of the knowledge of results
- keyboard provision and design for student response
- record of the responses for exercise critique

2.3.4.4.2 Procedures Monitoring Displays. It is desirable to provide the student immediate knowledge about the adequacy of performing lengthy, sequential procedural operations which are a part of the total job requirements. What is required is a display of the checklist or procedural sequence to be accomplished and some indication of the adequacy of the procedural performance as accrued (e.g., in-tolerance performance and errors of omission and commission in checklist completion). This is particularly appropriate to Operational Flight Trainers wherein the student must perform a number of precise checklist sequences involving both normal and emergency procedures throughout a mission cycle. In addition to the computer software requirements, a cockpit display is required (e.g., a CRT or a vertical screen) and a means for formatting, modifying and updating the procedures monitoring information.

An example of such a capability is the Trainee Monitoring System (TMS) currently employed in OFTs. Although the TMS serves as a performance measurement technique and now is only provided at the Instructor Station, it may also be installed in the trainee cockpit to provide supplemental information about performance not available in the job context. The trainee Monitoring System and the information requirements for procedures monitoring displays are described in detail in Chapter 3.4.8 in the section on Instructor Station Design.

2.3.4.4.3 Student Control of Instruction. It is desirable to provide the student greater control of events in training exercises than has been the traditional case. This involves a capability for initiating or deleting certain instructional events in order to enable the student to tailor problem difficulty to perceived needs or ability of the moment (self-pacing capability) or to the level of training being accomplished (based on instructor decisions defining the options available at a given time in the training sequence).

The design for student control of any instructional situation should provide the following capabilities (as required).

- freeze and unfreeze the trainer
- initiate and terminate preprogramed demonstrations in real time or slow time
- select and initiate training exercises or segments of an exercise (as appropriate)
- engage/disengage the platform motion system
- modify the initial conditions for a given training exercise

- alert the instructor that assistance is desired

- reset the trainer to the programed initial conditions for an exercise

- select displays of performance as appropriate (e.g., scoring information, error display)

- modify exercise difficulty by disabling an external forcing function (e.g., turbulence), or disabling a vehicle characteristic in order to simplify the control task (e.g., select a constant altitude in order to concentrate on heading control)

- place the device under automatic control wherein it performs within real-time programed tolerances or continues the steady-state condition prevailing at time of initiation (e.g., automatic co-pilot control of a simulated aircraft when the student is required to perform tasks incompatible with the control of the aircraft)

2.3.4.4.4 Student Information Display. Correlated with the problem control capability is the requirement to provide feedback of status and performance information. The following student information display capabilities should be provided in any design, as appropriate:

- indications of student-initiated control of instruction

    - problem freeze
    - motion system off
    - instructor acknowledgement of call for assistance
    - device is in demonstration mode
    - training exercise selection

- system status and performance information feedback indications

    - performance level or score
    - error out-of-tolerance
    - adaptive training score (as appropriate)
    - student may (now) assume control in training exercise
    - automatic playback of performance is in progress
    - student takeover from automatic playback condition
    - device is under automatic control (performing either within real-time programed tolerances or continuing the steady state condition prevailing at time of initiation)

- Display configuration
  - information formats and size
  - panel position in the trainee station
  - layout of the information array

2.3.4.4.5 Voice Alerts. The student may be alerted by means of audio signals that performance is outside of acceptable tolerance limits. Voice alerts have been employed most prominently in OFTs. For example, a recorded voice will indicate, via the intercom, when critical flight parameters (e.g., excessive pitch) are out-of-tolerance for a given maneuver or segment of flight.

The design considerations include the following.

- critical parameters per task or segment of the mission profile

- error tolerance envelopes per maneuver or flight condition

- means for determining message priority in out-of-tolerance performance

- message content and length

2.3.4.4.6 Command and Response Capability. This refers to means for accessing the computer to achieve various of the instructional features described in this section. In essence, the concern is for hardware capability to transmit student actions or decisions, i.e., data entry to or response to information or commands from the computer. The keyboard, employing pushbuttons in various arrays, is the technique currently most appropriate. The command and response capability in the trainee station serves several purposes, and the design requirements vary as a function of which purposes are to be served.

a. Provision is made for the student to recommend flight regimes to the computer; all flight changes are inputed through a keyboard. This purpose is served in the previously cited device 1D23 Air Navigation Trainer, wherein the student is provided controls and indications for the following: aircraft heading, altitude and speed control; engine(s) start and stop; and taxi, takeoff and landing. In general, the option affords the student the response capability for ordering commands although he is not a part of the dynamic response loop. For example, an EW trainee conducting an evasive maneuver to an airborne interceptor, simply orders (selects) a maneuver via keyboard input; the simulated own-aircraft completes the maneuver and automatically returns to the previous track.

b. Provision is made for the display of performance information to the student, e.g., the results of his response to interrogations from the computer. An example of this is the display of student output in response to programed messages (see item 2.3.3.3).

c. Provision is made for direct data entry to the computer, as applicable, to achieve the performance requirements in an exercise. Included also are requests for information needed in exercise performance. The design for the command and response capability should account for the following information requirements as relevant to the needs of the device under consideration.

- special keyboards vs. general multi-purpose keyboard
- functions and commands required
- values or units represented
- characters and symbols represented
- keyboard(s) array or matrix requirements
- coded overlays required for modes of operation
- keyboard(s) size and position in trainee station
- keyboard(s) utilization procedures

2.3.5 Post Note. The design of most complex training devices usually involves more than one level or approach to fidelity of simulation to achieve the desired instructional capability in the trainee station.

There are subsystems requiring high fidelity in physical simulation to provide the desired direct transfer of training from the device to the operational system counterpart.

Deliberately backing off from duplicating the characteristics of the operational situation is also a prevalent design option to achieve cost economies by reducing engineering fidelity without compromising training effectiveness.

Where the engineering state-of-the-art is less than adequate, we are forced to accept reductions in tolerances that are the best achievable.

There are also deliberate departures from realism which attempt to integrate training process and engineering fidelity. This differs from a cost-effective lowering of the engineering fidelity or a reduction in fidelity tolerances where the engineering state-of-the-art is less than adequate and is concerned with incorporating training technology into design.

Depending on the purpose of a training device and the basic design philosophy (replicas of operational counterparts, generalized trainers, part-task devices), no given level of fidelity is uniformly preferred at the expense of other options, and advantage accrues from employing combinations of the approaches mentioned above.

The four cases described in this section reflect the feature that several approaches may be incorporated effectively into a complex simulator. However, the four cases do not cover every situation since there are so many classes of training device. Also, human factors technical approach inputs in instances where the engineering state-of-the-art is less than adequate, suffer in accomplishment and hence the fashion is to accept current design practice with the rejoinder that further research is required. The supporting research requirement appropriate to this situation is discussed in Section IV of this report. Basically, however, the material provided in this section lends support to the human factors specialist in organizing the information requirements relevant to the engineering design of trainee stations.

SECTION III

INSTRUCTOR STATION DESIGN

3. INTRODUCTION

Substantial human factors contributions are made in instructor station design. Here, the emphasis is on the application of training technology to design, vis-a-vis behavior modification and transfer of training. The major aspect of design concerns the management of training involving the display, control and communications requirements in setting up, controlling, monitoring and evaluating instruction. The design requirement is to provide a capability for structuring training so that the definitive mission and system events can be installed and controls provided to insure that these events occur in prescribed ways at prescribed times. The bridge between student performance and instructional strategy is the measurement capability.

This section presents concepts related to, and techniques and procedures for defining the information requirements pertinent to instructor station design. The resultant information array serves as a basis for examining engineering alternatives (hardware and software design options) for achieving the instructional capabilities articulated in the MC.

Two concepts underly the human factors guidelines presented in this section and they are tacitly assumed in the discussions which follow. The first is the desirability of automating a number of key instructor functions. This instructional assistance enables more precise control of the instructional process and enhances the potential of a device as a training tool. The specific benefits subsumed under this concept are explicated throughout this section. The second is the desirability of the generalized (modular) construction of the instructor station. These two features, more than any other enhance the potential for flexibility and economy in design via the installation of a fundamental set of hardware (digital computer, I/O devices, etc.) and a software design pertinent not only to an individual device but to a class of training device. This enables substantial modifications in instructional capability within a given device or across similar devices without radical change in instructor station configuration. As the need for revision arises, the hardware is still applicable; only the software programing is modified, tailored to the new instructional objectives. Although the state-of-the-art has not advanced sufficiently to suggest these as ordinary design options, they nevertheless represent the goal to be achieved as data and technique are forthcoming from research and application.

3.1 MANUAL ADAPTIVE TRAINING CAPABILITY. As a prelude to the discussions which follow, it is worthy to note that the manual (normal) adaptive training capability is a desired human factors design goal for complex training devices (within the immediately foreseeable state-of-the-art); it most closely satisfies the assumptions and instructional goals set forth in this report.

The manual adaptive capability is defined by the options available to the instructor for keeping each student progressing through a sequence of instruction at that student's own achievement speed. The value of this (particularly in developing strategies to enhance the instruction of a group of students undergoing simultaneous but independent training) is the flexibility provided in the control of problem difficulty level and in the amount of instructor intercession required in effectively shaping individual behaviors. This approach takes advantage of computer assists in instruction, but relies on the instructor to initiate and control the actions required in developing instructional strategies tailored to the individual student. This is in contradistinction to computer controlled automation of the instructor functions wherein problem difficulty is automatically adjusted as a consequence of the immediately preceding performance of the student (see Chapter 3.4.10).

To achieve this capability, the following automated assists are provided.

- Standardization of Training--Preprogramed lesson plans are provided involving a series of standardized exercises graduated in difficulty with a capability for instructor intervention in prescribed ways to control the training process. This includes the override of defined mission events to accommodate students who perform below expectations for the given exercise and for the insertion of additional events in an exercise to accommodate students who exceed scenario requirements.

- Computer Assisted Measurement System--Automated evaluation and scoring with scoring criteria adjusted to the stage of training of each student provides error indications and information which are displayed at the instructor console. The instructor is able to select information on specific students on demand.

- Automated Monitor and Control Capability--Computer-driven multi-format CRT displays are provided at the instructor console presenting performance/error and mission status information in all relevant modes and in variable formats (both alpha-numeric and graphic).

- Instructional Controls--Controls are provided at the instructor station for monitoring student performance and system status and for initiating, continuing or modifying mission events to achieve desired training strategies.

- Hard Copy Records of Student Performance--Printouts of student performance information (time and event data, error deviations which exceed programed envelopes, summary information) are available on demand for use during and after a training exercise (for critique and for school record-keeping purposes).

The provision of these automated assists enables considerable flexibility in the shaping of desired behaviors. In addition to tailoring the learning progression to each student's abilities, variations in stimulus support can be provided as a function of stage of learning. For example, in early learning, maximum assistance can be provided all students as required (e.g., problem freeze, guidance, demonstration, reinstruction) overlaid on the standard mission scenario. As student proficiency increases, the stimulus supports are gradually withdrawn until the standard scenario prevails. Problem difficulty exceeding the requirements of a given scenario may also be installed to accommodate students who perform above the scenario standards.

Thus, the instructor is provided the opportunity to continually monitor all critical aspects of student performance. He is primarily a monitor and evaluator of student performance and has the control capability to alter features of the mission scenario commensurate with the training strategy. The basis for this is the automated performance monitoring, evaluation, and scoring system. The automated assists enable the following instructional options:

- Continue preprogramed mission, no action required.
- Override of defined programed mission events.
- Provide feedback of performance information to selected student(s) based on monitored information obtained from the displays. This may be in the form of knowledge of results of performance or cues to the student for enhancing performance.
- Halt the problem for any or all students and provide guidance, or halt the problem until all students have completed a mission phase; resume mission.
- Demonstration mode--provide a capability to demonstrate aspects of a task or maneuver to all students or to demonstrate specific characteristics of performance for any or all students during briefing or when performance is below expectations for the specific mission number; resume mission.
- Reinstruction mode--provide a capability to return to an earlier portion of the mission for any or all students when performance is below expectations for the mission. The reinstruction requires that the student perform again that which he has just completed (i.e., a segment, leg or portion of a leg of the mission).

- Error alert mode--when a student exceeds the error envelope in the mission for a class of error, a display of this information is provided the instructor and a computer-initiated problem freeze is a conventional outcome. The instructor options include: manual override of the freeze; accept freeze with procedures to continue (including the setting of new error tolerance envelopes); as well as those listed above in order to develop the training strategy for the student in question.

- Insert new events into the exercise--when a student's performance exceeds the mission scenario requirements, the instructor has the option of inserting new events in addition to those in the preprogramed scenario. This provides for a controlled increase in problem difficulty for the purpose of keeping any student at the threshold of his ability at any given time.

3.2 BASIC APPROACH. Consistent with Section II, the human factors effort is to determine the information requirements which engineering must account for in proposing technical approaches to the design for instruction. The derivation of the information requirements and the instructional capabilities relative to instructor station design is based on the range of functions performed by the instructor. Basically, the analyses concern the following: what information is required for monitoring the total training situation; what controls are needed to display appropriate information to the student and to select appropriate information about student performance; what instructional options are available to the instructor in monitoring, evaluating and controlling training; and what modes, formatting requirements, speed and flexibility of displays are required to enable instructional control?

The display, control and communications requirements are also examined in light of the functions performed in pre-exercise setup, enroute exercise operations and post-exercise operations. Once completed, these information requirements are utilized by the human factors specialist in collaborating with engineering specialists to determine the technical approaches for implementation consistent with the nature of the contemplated training system.

The remainder of this section is devoted to an analysis of instructor functions and the information requirements subsumed under each function as a basis for determining the design of the instructor station. Table 7 presents a listing of the range of instructor functions that must be accomplished (pertinent to most devices in the NTDC inventory). The listing is generic; any given device does not invoke the total list of functions. Each function is, however, pertinent in some measure to one or more devices or device classes. For each of the functions listed in Table 7, a description is given of where in the training exercise or total training sequence it pertains, whether the function is specific to a training device class or general to most training devices, and what instructional capability or level of instructor involvement is provided by the function.

The information requirements associated with each of these functions are discussed in the detail necessary to permit the correlation of these needs with proposed engineering solutions. The reader should determine which of the functions (and the specific instructional implications) pertains to his specific design situation, concentrate on these and ignore the remainder (this is in keeping with our intent to provide "guideline" support for most any training device situation).

TABLE 7. INSTRUCTOR FUNCTIONS

Functions Performed	Where Pertinent In Training Exercise or Total Training Sequence	Specific or General Function	Instructor Station Capability/Instructor Involvement
Initialize system, confidence checks	Pre-exercise	All training devices	Power, system checks
Select and mount scenario tapes	Pre-exercise (including review of scenario)	Preprogramed lesson plans	Automatic (computer program)
Modify or construct new scenarios	Pre-exercise	Preprogramed lesson plans	Automatic (computer program)
Operate trainee monitor system (TMS) (DRED, EDIT, INCH modes)	Off-line	2 series training devices, automated performance recording systems	
Activate trainer and verify operability	Pre-exercise	All training devices	
Select mode of trainer operation	Pre-exercise	All training devices	
Trainee station activation	Pre-exercise	All training devices	Provide power, motion system activation/deactivation, playback of control performance, automatic control of trainer (simulated co-pilot control) instruct hard copy printer (as appropriate)

TABLE 7. INSTRUCTOR FUNCTIONS (Continued)

Functions Performed	Where Pertinent In Training Exercise or Total Training Sequence	Specific or General Function	Instructor Station Capability/Instructor Involvement
Set up initial conditions (problem parameters)	Pre-exercise	Lesson plans with interdependent parameters (manual or preselected data sets) (Dependent on device class)	Individual parameter selection or single control for preselected data set
Insert preprogramed value/range for computer control of parameter deviation	Pre-exercise	Automated performance recording systems	
Student briefing	Pre-exercise, or at Comex	All training devices	Verbal or in-station automatic
Monitor, control and evaluate student(s) performance	Enroute exercise (from Comex)	All training devices	Manual, semi-automatic, or automatic systems
• Demonstration mode	Pre-exercise or enroute (as appropriate)	Computer controlled	Instructional guidance
• Control of problem events	Enroute exercise (as required)	Time and event control of problem manipulatables	Manual insertion, manipulation (as required)

TABLE 7. INSTRUCTOR FUNCTIONS (Continued)

Functions Performed	Where Pertinent In Training Exercise or Total Training Sequence	Specific or General Function	Instructor Station Capability/Instructor Involvement
. Operate and monitor trainee monitor system (normal procedures and malfunctions insertion in problem mode)	Enroute exercise (as appropriate)	Automated procedural performance recording systems (e.g., 2 series trainers checklist procedures)	
. Select and insert malfunctions/ emergencies	Enroute exercise (as appropriate)	Manual systems	Manual insertion for modifying problem difficulty
. Error alert mode	Automatic problem freeze when student is out of preset error tolerance	Automated performance recording systems	Computer initiated
. Manual override of preprogramed problem events	Enroute (as appropriate) to accommodate errant student(s)	Automated systems	Modify problem difficulty
. Override of preprogramed KR, guidance	Enroute (as appropriate)	Automated systems	Control of stimulus supports

TABLE 7. INSTRUCTOR FUNCTIONS (Continued)

Functions Performed	Where Pertinent In Training Exercise or Total Training Sequence	Specific or General Function	Instructor Station Capability/Instructor Involvement
• Insertion of new events into standardized preprogramed scenario	Enroute (as appropriate) to accommodate student(s) exceeding performance standards	Automated systems	Modify problem difficulty --instructor initiated
• Modify error tolerance value/range for computer control of parameter deviation	Enroute and across successive exercises (as appropriate)	Automated systems	Instructor initiated
• Monitor and control all vehicle subsystems	Enroute exercise (as appropriate)		Display-control capability
• Problem halt, override, restart, freezing particular parameters	Enroute exercise (as appropriate)	All training devices	Control of instruction during exercise
• Reinstruction mode	Direct below-standard student(s) to reaccomplish segment of scenario	Automated systems	Development of training strategy for student (resetting of mission scenario capability)

TABLE 7. INSTRUCTOR FUNCTIONS (Continued)

Functions Performed	Where Pertinent In Training Exercise or Total Training Sequence	Specific or General Function	Instructor Station Capability/Instructor Involvement
• Problem speed control	Enroute exercise (as appropriate)		
• Specific stimuli presentation	Enroute exercise (as appropriate)	Automated systems	Messages calling for specific student behavior (computer initiated, scored and KR provided student)
• Monitor student performance	Enroute exercise (as appropriate)	Automated systems	On-demand information displays in all appropriate modes and formats
• Operate performance recording systems	Enroute exercise (as appropriate)	2 series training devices (e.g., flight plan recorder)	Displays and controls for information requests specific to various devices
• Monitor the use of communications and radio aids	Enroute exercise (as appropriate)	2 series training devices	
• Manual control of vehicles (adversary)	Enroute exercise (as appropriate)	2, 14, 20 series training devices	Instructor-controlled aircraft, submarine

TABLE 7. INSTRUCTOR FUNCTIONS (Continued)

Functions Performed	Where Pertinent In Training Exercise or Total Training Sequence	Specific or General Function	Instructor Station Capability/Instructor Involvement
• Select and interrogate performance and error information	Enroute exercise (as appropriate)	Automated performance recording systems	CRT displays in various formats; hard copy printouts in selected formats, selection by student, data class, etc. (on demand)
Communications			Verbal-instructions/KR/guidance
• With student(s) operator, remote instructor	Enroute exercise	All training devices	
• Ground station communications simulation		2 series training devices	Instructor operation (Ex: GCA, Data Link)
• Other vehicle/unit simulation			Instructor control
Select hard copy printouts of performance	Post-exercise	Automated systems	Performance recording, tape records
Operate trainee monitor system (TMS) (REPLAY mode)	Post-exercise	Automated performance recording systems (2 series training devices)	Instructor control

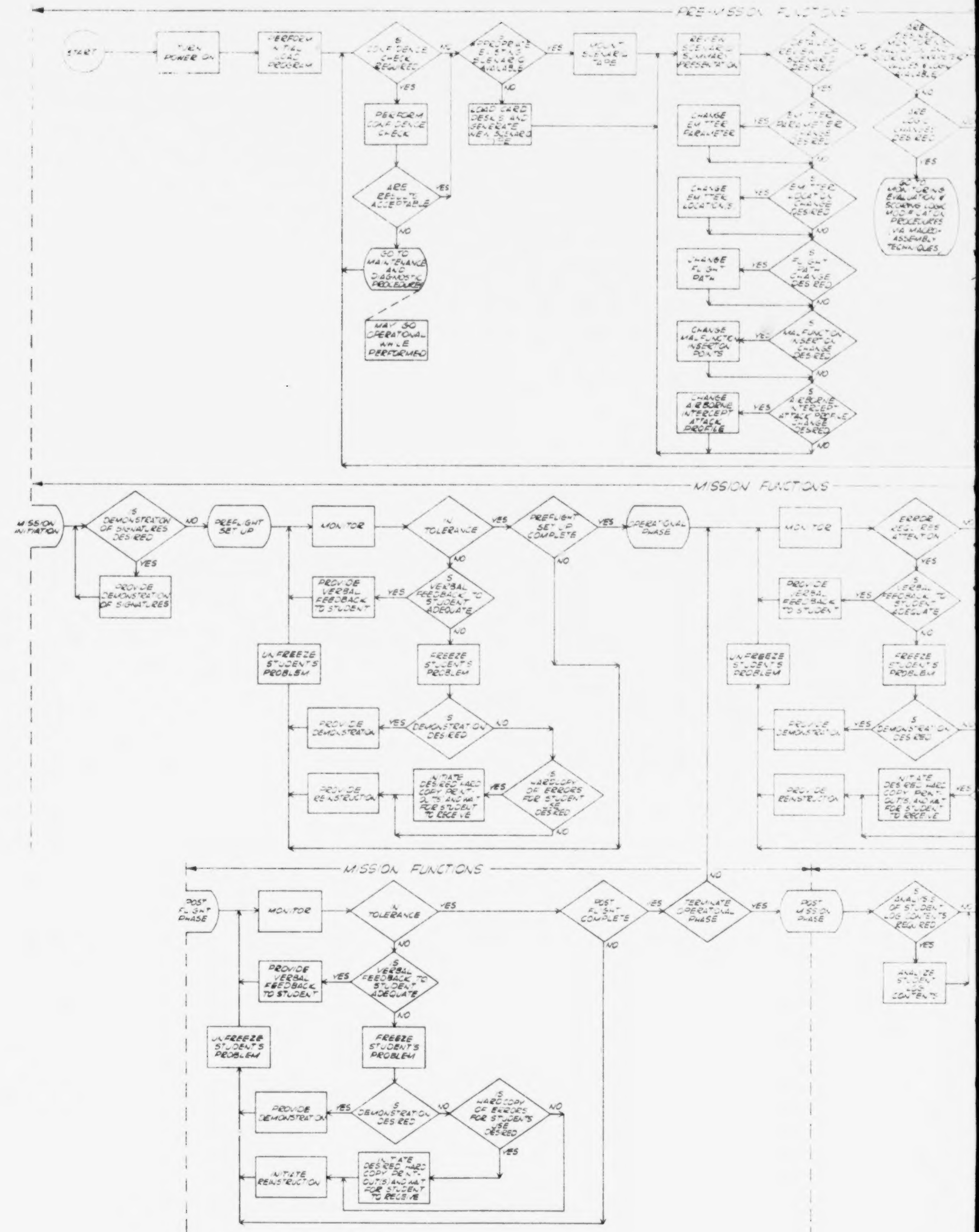
TABLE 7. INSTRUCTOR FUNCTIONS (Continued)

Functions Performed	Where Pertinent In Training Exercise or Total Training Sequence	Specific or General Function	Instructor Station Capability/Instructor Involvement
System shutdown	Post-exercise	All training devices	
Recycle system to pre-mission phase	Post-exercise	Trainers with automated preprogramed exercise scenarios	
Critique	Post-exercise	All training devices	Required equipments (reconstruction, audio-visual playback capabilities)

3.3 INSTRUCTOR FUNCTIONS FLOW ANALYSIS. When the specific instructional functions to be provided are identified (Table 7) and prior to beginning the detailed analyses of the information requirements per function, the human factors specialist should develop an overview of the instructor involvement in the training system in order to consolidate thinking about the design philosophy and to aid in the further definition of design requirements for the instructor station. This is accomplished in the form of a functions flow analysis which depicts a summary of the desired sequence of instructional operations and the options available to the instructor in developing a training strategy. This enables the human factors specialist to "put together" the candidate design features for instructor involvement in structuring and controlling training. Figure 9 provides an example of a functions flow analysis. The example is for an airborne Electronic Warfare Training System. This is semi-automatic system (4 to 1 student-to-instructor ratio) having a number of computer assists in instructional capability. The device characteristics include the following:

- preprogramed mission scenarios graduated in problem difficulty
- automated monitoring, evaluation and scoring capability
- computer driven CRT displays for presenting all relevant performance and mission information
- off-line modification and generation of scenarios
- hard-copy printouts of student performance
- manual adaptive capability (the instructor has the means for adjusting task difficulty so that it is appropriate to each student's level of skill; the preprogramed scenarios are modifiable enroute enabling the achievement of a strategy for training both for the above and the below standards performer).

The functions flow diagram is continually improved throughout the instructor station information analysis phase. It serves importantly as a check for design in that 1) the information requirements are correlated with the operations in the diagram, and 2) all the blocks depicted in the final diagram must be accounted for in the selected engineering approaches. Thus, the functions flow diagram serves as a human factors "test and tryout" vehicle prior to interactions with the engineering specialists. It also serves as the initial point of contact between human factors and engineering in defining the technical approaches to device design, i.e., "role play" the scenario with engineers to place the total instructional system in perspective prior to more detailed considerations.


PRE-MISSION FUNCTIONS
START
TURN POWER ON
PERFORM INITIAL LOAD PROGRAM
IS CONFIDENCE CHECK REQUIRED
NO
YES
PERFORM CONFIDENCE CHECK
ARE RESULTS ACCEPTABLE
YES
NO
GO TO MAINTENANCE AND DIAGNOSTIC PROCEDURES
MAY GO OPERATIONAL WHILE PERFORMED
IS APPROPRIATE EXISTING SCENARIO AVAILABLE
YES
NO
LOAD CARD DECKS AND GENERATE NEW SCENARIO TAPE
MOUNT SCENARIO TAPE
REVIEW SCENARIO SUMMARY PRESENTATION
IS DETAILED REVIEW OF SCENARIO DESIRED
NO
YES
IS EMITTER PARAMETER CHANGE DESIRED
YES
CHANGE EMITTER PARAMETER
NO
IS EMITTER LOCATION CHANGE DESIRED
YES
CHANGE EMITTER LOCATIONS
NO
IS FLIGHT PATH CHANGE DESIRED
YES
CHANGE FLIGHT PATH
NO
IS MALFUNCTION INSERTION CHANGE DESIRED
YES
CHANGE MALFUNCTION INSERTION POINTS
NO
IS AIRBORNE INTERCEPT ATTACK PROFILE CHANGE DESIRED
YES
CHANGE AIRBORNE INTERCEPT ATTACK PROFILE
NO
ARE DESIRED MONITORING, EVALUATION & SCORING PARAMETER VALUES & LOGIC AVAILABLE
NO
ARE LOGIC CHANGES DESIRED
YES
GO TO MONITORING EVALUATION & SCORING LOGIC MODIFICATION PROCEDURES (VIA MACRO-ASSEMBLY TECHNIQUES)
MISSION FUNCTIONS
MISSION INITIATION
IS DEMONSTRATION OF SIGNATURES DESIRED
NO
YES
PROVIDE DEMONSTRATION OF SIGNATURES
PREFLIGHT SET UP
MONITOR
IN TOLERANCE
YES
NO
PREFLIGHT SET UP COMPLETE
YES
NO
IS VERBAL FEEDBACK TO STUDENT ADEQUATE
YES
PROVIDE VERBAL FEEDBACK TO STUDENT
NO
FREEZE STUDENT'S PROBLEM
UNFREEZE STUDENTS' PROBLEM
IS DEMONSTRATION DESIRED
YES
NO
PROVIDE DEMONSTRATION
IS HARDCOPY OF ERRORS FOR STUDENT USE DESIRED
YES
NO
INITIATE DESIRED HARD COPY PRINT-OUTS AND WAIT FOR STUDENT TO RECEIVE
PROVIDE REINSTRUCTION
OPERATIONAL PHASE
MONITOR
ERROR REQUIRES ATTENTION
YES
IS VERBAL FEEDBACK TO STUDENT ADEQUATE
YES
PROVIDE VERBAL FEEDBACK TO STUDENT
NO
FREEZE STUDENT'S PROBLEM
UNFREEZE STUDENT'S PROBLEM
IS DEMONSTRATION DESIRED
YES
PROVIDE DEMONSTRATION
INITIATE DESIRED HARD COPY PRINT-OUT(S) AND WAIT FOR STUDENT TO RECEIVE
YES
PROVIDE REINSTRUCTION
MISSION FUNCTIONS
POST FLIGHT PHASE
MONITOR
IN TOLERANCE
YES
NO
IS VERBAL FEEDBACK TO STUDENT ADEQUATE
YES
PROVIDE VERBAL FEEDBACK TO STUDENT
NO
FREEZE STUDENT'S PROBLEM
UNFREEZE STUDENT'S PROBLEM
IS DEMONSTRATION DESIRED
YES
NO
PROVIDE DEMONSTRATION
IS HARDCOPY OF ERRORS FOR STUDENT'S USE DESIRED
NO
YES
INITIATE DESIRED HARD COPY PRINT-OUT(S) AND WAIT FOR STUDENT TO RECEIVE
INITIATE REINSTRUCTION
POST FLIGHT COMPLETE
YES
NO
TERMINATE OPERATIONAL PHASE
YES
NO
POST MISSION PHASE
IS ANALYSIS OF STUDENT LOG CONTENTS REQUIRED
YES
ANALYZE STUDENT LOG CONTENTS

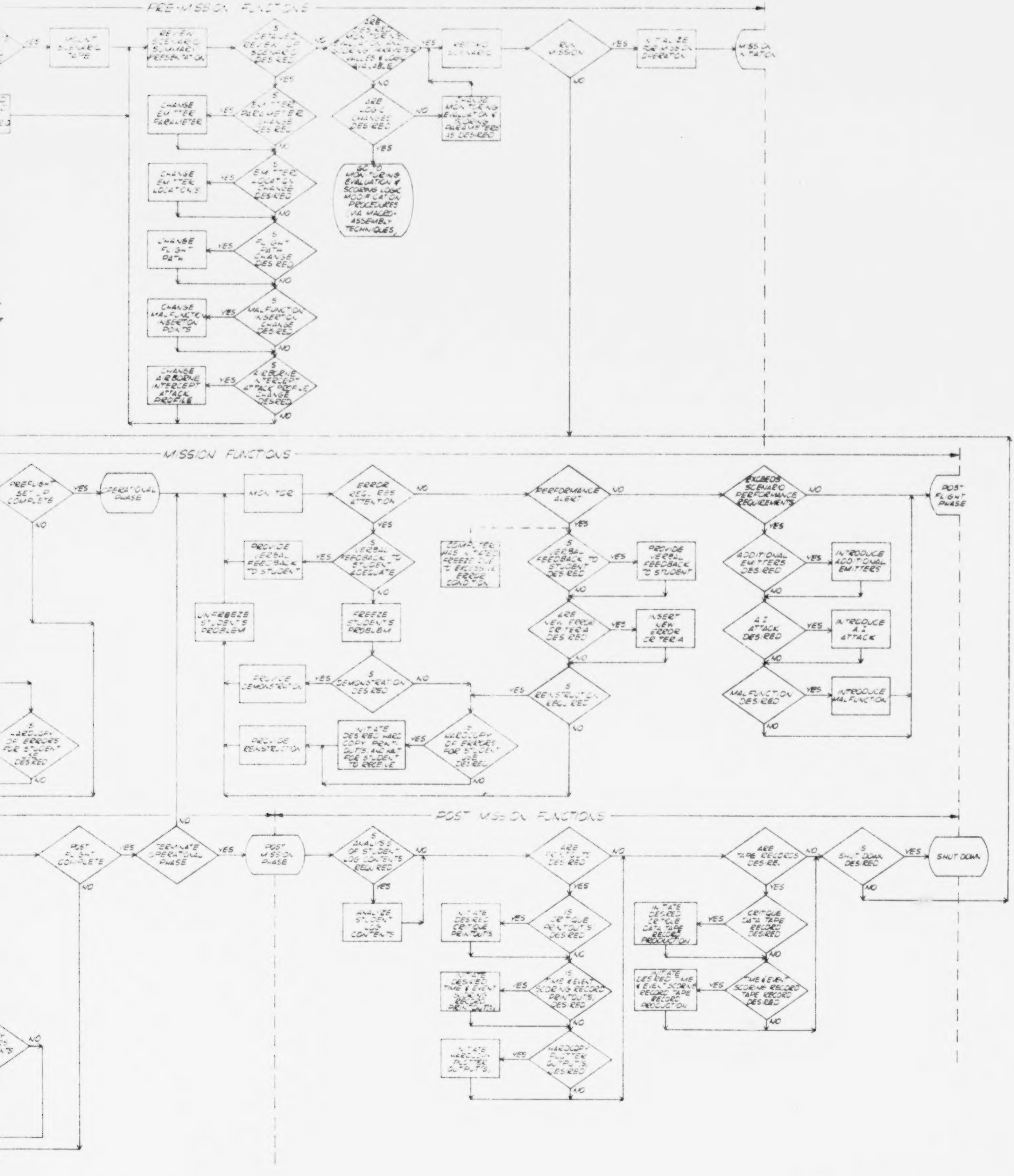

PRE-MISSION FUNCTIONS
YES
MOUNT SCENARIO TAPE
REVIEW SCENARIO SUMMARY PRESENTATION
IS DETAILED REVIEW OF SCENARIO DESIRED
NO
ARE DESIRED MONITORING, EVALUATION AND SCORING PARAMETER VALUES & LOGIC AVAILABLE
YES
RECORD SCENARIO
RUN MISSION
YES
INITIALIZE FOR MISSION OPERATION
MISSION INITIATION
NO
YES
IS EMITTER PARAMETER CHANGE DESIRED
YES
CHANGE EMITTER PARAMETER
NO
ARE LOGIC CHANGES DESIRED
NO
CHANGE MONITORING EVALUATION & SCORING PARAMETERS AS DESIRED
YES
GO TO MONITORING EVALUATION & SCORING LOGIC MODIFICATION PROCEDURES (VIA MACRO-ASSEMBLY TECHNIQUES)
IS EMITTER LOCATION CHANGE DESIRED
YES
CHANGE EMITTER LOCATION(S)
NO
IS FLIGHT PATH CHANGE DESIRED
YES
CHANGE FLIGHT PATH
NO
IS MALFUNCTION INSERTION CHANGE DESIRED
YES
CHANGE MALFUNCTION INSERTION POINTS
NO
IS AIRBORNE INTERCEPT ATTACK PROFILE CHANGE DESIRED
YES
CHANGE AIRBORNE INTERCEPT ATTACK PROFILE
NO
MISSION FUNCTIONS
PREFLIGHT SET UP COMPLETE
YES
NO
OPERATIONAL PHASE
MONITOR
ERROR REQUIRES ATTENTION
NO
YES
IS VERBAL FEEDBACK TO STUDENT ADEQUATE
YES
PROVIDE VERBAL FEEDBACK TO STUDENT
NO
FREEZE STUDENT'S PROBLEM
UNFREEZE STUDENT'S PROBLEM
IS DEMONSTRATION DESIRED
YES
PROVIDE DEMONSTRATION
NO
IS HARDCOPY OF ERRORS FOR STUDENT USE DESIRED
YES
INITIATE DESIRED HARD COPY PRINTOUT(S) AND WAIT FOR STUDENT TO RECEIVE
PROVIDE REINSTRUCTION
NO
COMPUTER HAS INITIATED FREEZE DUE TO EXCESSIVE ERROR CONDITION
PERFORMANCE ALERT
NO
YES
IS VERBAL FEEDBACK TO STUDENT DESIRED
YES
PROVIDE VERBAL FEEDBACK TO STUDENT
NO
ARE NEW ERROR CRITERIA DESIRED
YES
INSERT NEW ERROR CRITERIA
NO
IS REINSTRUCTION REQUIRED
YES
NO
EXCEEDS SCENARIO PERFORMANCE REQUIREMENTS
NO
YES
ADDITIONAL EMITTERS DESIRED
YES
INTRODUCE ADDITIONAL EMITTERS
NO
A.I. ATTACK DESIRED
YES
INTRODUCE A.I. ATTACK
NO
MALFUNCTION DESIRED
YES
INTRODUCE MALFUNCTION
NO
POST FLIGHT PHASE
IS HARDCOPY OF ERRORS FOR STUDENT USE DESIRED
NO
POST MISSION FUNCTIONS
POST FLIGHT COMPLETE
YES
NO
TERMINATE OPERATIONAL PHASE
YES
NO
POST MISSION PHASE
IS ANALYSIS OF STUDENT LOG CONTENTS REQUIRED
NO
YES
ANALYZE STUDENT LOG CONTENTS
ARE PRINTOUTS DESIRED
NO
YES
IS CRITIQUE PRINTOUT(S) DESIRED
YES
INITIATE DESIRED CRITIQUE PRINTOUTS
NO
IS TIME & EVENT SCORING RECORD PRINTOUT(S) DESIRED
YES
INITIATE DESIRED TIME & EVENT SCORING RECORD PRINTOUT(S)
NO
HARDCOPY PLOTTER OUTPUT(S) DESIRED
YES
INITIATE HARDCOPY PLOTTER OUTPUT(S)
NO
ARE TAPE RECORDS DESIRED
NO
YES
CRITIQUE DATA TAPE RECORD DESIRED
YES
INITIATE DESIRED CRITIQUE DATA TAPE RECORD PRODUCTION
NO
TIME & EVENT SCORING RECORD TAPE RECORD DESIRED
YES
INITIATE DESIRED TIME & EVENT SCORING RECORD TAPE RECORD PRODUCTION
NO
IS SHUT DOWN DESIRED
YES
NO
SHUT DOWN

Figure 9. Functions Flow Analysis.

3.4 INFORMATION REQUIREMENTS BASED ON FUNCTIONS PERFORMED. The specific display, control and communications requirements that influence the engineering design choices for a contemplated training device are detailed next. These are presented as guidelines for the human factors analyses of the information requirements that must be accounted for in the decision to initiate the development of a training device. In providing inputs to a specific technical approach study, the human factors specialist examines only those functions described in this section that pertain to the device under consideration (as specified in the MC documentation).

The information analyses requirements are presented in a series of chapters; each chapter considers a basic commonality in content which is related to specific functions performed in the instructional process. Within each chapter, relevant design options are identified and analyzed. The analysis centers on: the use and training value of the design option, the information requirements that must be accounted for in implementing design, and a discussion of the assumptions and the constraints involved in engineering implementation.

The congeries of design issues are portrayed in the remainder of this section. Fourteen separate chapters are devoted to articulating the information requirements pertinent to the structure and control of training. The chapters are organized as follows:

- Off-line Preparation for Trainer Use
- Training Problem Formulation and Presentation
- Data Handling and Display
- Information Display Requirements for Monitor, Evaluation and Scoring of Performance
- Control Capabilities for Monitor, Evaluation and Scoring of Performance
- Instructional Options Capability
- Measurement System Design
- Procedural Performance--Display and Recording
- Capability and Controls for Inputs to the Computer
- Software Capability for Developing Automated Adaptive Strategies

- Automated Verbal Messages
- Communications
- Post-Exercise Instructional Capability
- Human Engineering Design

In addition, a summary of the information requirements relevant to training device design is provided in a checklist format in Table 8. This sets forth the sequence of activities to be accomplished in order to achieve the human factors inputs in support of the Technical Approach determination. Each information item in the series is individually considered via the appropriate column in the checklist. In addition, the specific paragraphs in the text which are appropriate to each item in the checklist are identified. This correlation of checklist items with text material provides a convenient reference for the human factors specialist. The checklist serves as an aid for organizing the information requirements prior to interacting with engineering specialists in technical approach development.

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
A. Off-line Preparation for Trainer Use			
1. checkout of the trainer			3.4.1.1, 3.4.9
2. training problem selection and setup			3.4.1.2
3. modification of existing programed scenarios			3.4.1.2, 3.4.9
4. generation of preprogramed scenarios			3.4.1.3, 3.4.2, 3.4.9
5. readiness for on-line operations			3.4.1.4
B. Training Problem Development			
1. job content definition (preprogramed exercises)			3.4.2.1.1
2. organization of training exercises (preprogramed)			3.4.2.1.2, 3.4.2.1.3
3. definition of initial conditions			3.4.2.2
4. means for installing initial conditions			3.4.2.2
5. automated briefing (pre-exercise)			3.4.2.3
C. Trainer Operation			
1. off-line trainer operating modes			3.4.1.1, 3.4.7.1.1, 3.4.7.2, 3.4.8.1

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
2. on-line modes of operation			3.4.2, 3.4.3, 3.4.5.1, 3.4.6, 3.4.8, 3.4.9, 3.4.12, 3.4.13
D. Automated Assists for Instructional Control			
1. preprogramed standard lesson plans			3.4.2
2. computer assisted measurement system			3.4.7
3. automated monitor and control capability			3.4.3, 3.4.4, 3.4.5
4. automatic error alerts			3.4.6.4.1
5. autopilot program			3.4.6.4.3
6. hard copy performance records			3.4.7, 3.4.13.1
E. Instructional Control Options			
1. selection of display system modes			3.4.2.4, 3.4.5, 3.4.6.1
2. selection of displays for monitoring and evaluating student performance			3.4.5.1
3. modify preprogramed scenarios divising and exercise			3.4.2, 3.4.3

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
4. guidance supports			3.4.6.2
• demonstration programs			3.4.6.2.1
• reinstruction			3.4.6.2.2
5. specific stimulus presentation			3.4.6.3
6. assists in problem control			3.4.6.4
• automatic error alerts			3.4.6.4.1
• individual parameter freeze			3.4.6.4.2
• autopilot program			3.4.6.4.3
7. supplemental assists (e.g., CCTV)			3.4.6.4.4
8. knowledge of results			3.4.6.4.5
9. hard copy records of student performance			3.4.13.1
F. Specific Display Requirements			
1. trainee station displays			3.4.4
2. device status and operation			3.4.4
3. auxiliary information			3.4.4
4. communications			3.4.12
5. monitoring and recording			3.4.7
6. mission displays			3.4.3.3
7. visual factors in displays			3.4.3.2.1,
• legibility requirements			3.4.3.2.2
• speed and flexibility in adjusting display content			

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
8. procedural (checklist) performance displays			3.4.8
G. Information Content of Displays			
1. mission data			3.4.3, 3.4.4
2. display of student history			3.4.3, 3.4.4
3. mission/scenario area			3.4.3, 3.4.4
4. own-vehicle and support/ friendly vehicles			3.4.3, 3.4.4
5. mission events/installations			3.4.3, 3.4.4
6. target data			3.4.3, 3.4.4
7. total situation display			3.4.3, 3.4.4
8. environment			3.4.3, 3.4.4
9. console operating modes			3.4.2, 3.4.3, 3.4.4
10. indication of system state or mode of operation and phase or point in the mission or exercise			3.4.3, 3.4.4
11. location (geographic) of all students in the exercise			3.4.3, 3.4.4
12. variance of vehicles about the ideal track			3.4.3, 3.4.4, 3.4.7
13. status of events initiated in the trainee station			3.4.3, 3.4.4

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
14. indication of student/team control or tactical action and consequences of the action			3.4.3, 3.4.4
15. indication (and time) of student/team detection and identification of target, from onset			3.4.3, 3.4.4
16. indication of instructor actions, initiated and under control			3.4.3, 3.4.4
17. instructor control of vehicles			3.4.3, 3.4.5
18. performance information on each student or team (error/status/activity)			3.4.3, 3.4.4
19. indication of out-of-tolerance performance			3.4.3, 3.4.7
20. indication of vehicle(s) out-of-tolerance			3.4.3, 3.4.4
21. indication of adequacy of student procedural performance			3.4.3, 3.4.4, 3.4.8
22. indication of student/team error deviations from programed tolerances			3.4.3, 3.4.4, 3.4.7
23. types, number of communications errors			3.4.3, 3.4.4, 3.4.12
24. indications of actions requested of a student			3.4.3, 3.4.4

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
25. indication of malfunctions/ emergencies/failures			3.4.3, 3.4.4
26. indications of critical time and event happenings during exercise			3.4.3, 3.4.4
27. status information requests from the student			3.4.3, 3.4.4
H. Control Functions			
1. trainer and display system mode selection (off-line and on-line)			3.4.3.4
2. scenario generation or modification (off-line)			3.4.1.2, 3.4.1.3, 3.4.9
3. initial condition setup			3.4.2.2
4. ancillary and power supply controls			3.4.5
5. mission/instructional control (enroute exercise)			3.4.5
6. control of procedural (checklist) performance			3.4.8
7. inputs to the computer			3.4.9
I. Specific Control Capability for Monitoring, Evaluating and Scoring Performance			
1. device operation			3.4.4, 3.4.5

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
2. trainee station controls			3.4.5
3. means for displaying student history			3.4.3., 3.4.5
4. means for positioning units in an exercise			3.4.5
5. environment (media) controls			3.4.5
6. means for inserting and manipulating targets in an exercise			3.4.5
7. means for inserting parameters and events at prescribed times in an exercise			3.4.5, 3.4.6
8. means for inserting non-programed events or eliminating programed events in preprogramed scenarios			3.4.5, 3.4.6
9. means for selecting CRT display modes and formats; page selection			3.4.4, 3.4.5
10. selection of specific performance information (e.g., individual/all students, error data, system performance data)			3.4.3, 3.4.5
11. means for freezing individual parameters in an exercise			3.4.5, 3.4.6.4.2
12. means for inserting/denying failures or emergencies			3.4.5

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
13. means for direct access to device computation system			3.4.5, 3.4.9
14. communications controls			3.4.12.3, 3.4.5
15. means for controlling target or support vehicles			3.4.5
16. controls to tally defined complex responses of students			3.4.5, 3.4.7
17. means for recycling the system in automated exercises • reinstruction • remedial branching • recycle students who exceed scenario requirements			3.4.5, 3.4.6
18. means for initiating and terminating demonstrations			3.4.5, 3.4.6
19. means for selecting performance information to be scored and recorded			3.4.5, 3.4.7.5
20. means for inserting changes in present error tolerances			3.4.5, 3.4.7
21. means for monitoring and controlling student procedural performance			3.4.5, 3.4.8
22. means for selecting hard copy records of student performance			3.4.5, 3.4.7.5.2, 3.4.13.1

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
23. interlock controls between instructor station and TDO console (to avert unauthorized insertion of additional parameters into preprogramed scenario)			3.4.5
24. means for changing, or modifying mission areas			3.4.5
J. Measurement System Design			
1. selection of what to measure			3.4.7.1
2. selection of measures			3.4.7.2
3. establishment of performance standards			3.4.7.3
4. establishment of performance tolerance envelopes for computer scoring			3.4.7.3
5. capability for modifying computer scoring criteria			3.4.7.3.1
6. sampling of performance strategies			3.4.7.4
7. performance data sampling rates			3.4.7.4.1
8. organization of the measurement data			3.4.7.4.2
9. display of measurement information during the exercise			3.4.7.5

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
10. hard copy computer outputs			3.4.7.5.2, 3.4.13.1
11. automatic quality control of training data			3.4.7.6.2
K. Display and Control of Procedural (Checklist) Performance			
1. modes of operation			3.4.8.1, 3.4.8.2
2. definition of the procedures and the step sequences for each procedure			3.4.8.2.1
3. display presentation formats			3.4.8.1.3, 3.4.8.2.1
4. control requirements			3.4.8.1.3, 3.4.8.2
L. Data Entry to the Computer			
1. off-line modes of operation			3.4.9
2. enroute problem control			3.4.9
3. display modes associated with the input device			3.4.9
4. definition of sequences in operating the input device in all modes			3.4.9
M. Automated Adaptive Simulation Capability			
1. selection of adaptive variables			3.4.10
2. selection of measures			3.4.10.4

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
3. establishment of error tolerances			3.4.10.4
4. selection of an adaptive logic			3.4.10.5
5. establishment of the performamce sampling periods			3.4.10.5
6. means of displaying performance information			3.4.10.6
N. Automated Verbal Messages			
1. selection of appropriate instructional situations			3.4.11
2. definition of task structure			3.4.11
3. selection of appropriate word universe			3.4.11
4. definition of number of messages required and message structure			3.4.11
5. assignment of message priorities			3.4.11
6. selection of timing sequence for successive messages for the same system state			3.4.11
7. means for modifying messages and for overriding programed messages			3.4.11

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

	Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
O.	Communications			
	1. extent of representation			3.4.12.1
	2. instructor monitoring capability			3.4.12.1
	3. display of communications status			3.4.12.1
	4. capability for common audio network, simultaneous communications or extra vehicle communications			3.4.12.1
	5. operating controls			3.4.12.3
	6. controls for recording audio performance of the student			3.4.12.3
	7. controls for activating prerecorded verbal messages			3.4.12.3
P.	Post-Exercise Instructional Capability			
	1. types of hard copy performance records required • critique • quality control			3.4.13.1
	2. information to be recorded			3.4.13.1
	3. formatting of retrievable records			3.4.13.1
	4. means for selecting programed performance variables, sampling rates and formats			3.4.13.1

TABLE 8. CHECKLIST OF INFORMATION REQUIREMENTS FOR INSTRUCTOR STATION DESIGN (Continued)

Checklist Item	Accounted for (Y) Yes (N) No	N/A	Pertinent Paragraphs in the Text
5. video recording and playback capability • selection of content • means of control for start and exit in playback mode • selection of playback mode speed • means to access desired portions of the video record for playback			3.4.13.2.
6. pictorial reconstruction of just completed exercises (for critique)			3.4.13.3.
7. audio records for critique			3.4.13.4.
Q. Human Engineering Design			
1. application of human engineering criteria and design recommendations as specified in MIL STD 1472A, MIL H 46855 and other appropriate specifications • layout and configuration • display and control groupings and positions • panel markings • lighting • workspace constraints			3.4.14.

3.4.1 OFF-LINE PREPARATION FOR TRAINER USE

A number of pre-mission operations must be considered in determining the technical approaches to design. Of concern are the functions performed by the instructor (and/or the training device operator) off-line, prior to initiating a given training exercise. The design issues involve the information requirements for the following:

- checkout of the trainer
- problem selection and setup
- generation of new scenarios
- readiness for on-line operations.

Figure 9 provides an example of the kinds of pre-mission instructor operations performed for a semi-automated EW trainer prior to mission initiation. It also indicates the options available for recycling the trainer to another previous stage or to another exercise in the training sequence instead of shutting the trainer down. Figure 10 provides another example of the possible operations to be performed by the instructor (or TDO) prior to mission initiation for device 1D23, Air Navigation Trainer.

3.4.1.1 Checkout of the Trainer. The instructor is required to monitor and control the trainer checkout to determine visually that the simulator is ready for operation. This is accomplished in accordance with the Daily Readiness (DRED) Check programs. Each of the trainer systems to be tested are activated by simulated inputs, with system outputs compared with predetermined values. The information requirements for design include:

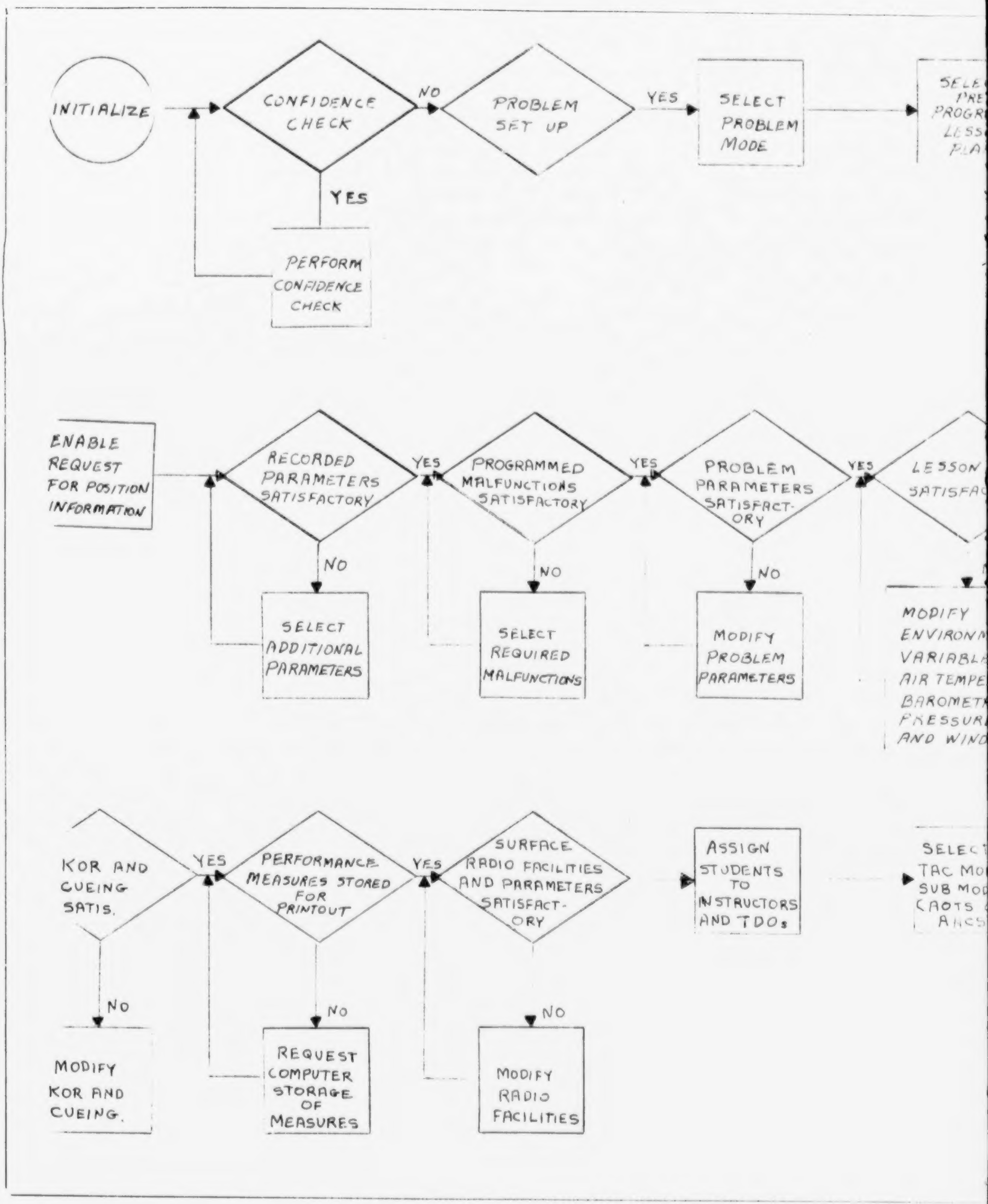
- Selection of automatic or manual operation in the DRED mode.

- Layout of the function keyboard overlay for the DRED mode. Figure 11 depicts a DRED mode overlay proposed for device 2F101, T-2C Operational Flight Trainer (Goodyear 1971).

- The procedures and associated controls for individual system tests, total system test and fault isolation.

- The content and format of the test results displayed on the CRT and on hard copy printout (as required).

3.4.1.2 Problem Selection and Setup. This off-line function includes the selection and mounting of an existing preprogramed scenario or the modification of an existing scenario to achieve a current training objective.


INITIALIZE
CONFIDENCE CHECK
NO
YES
PERFORM CONFIDENCE CHECK
PROBLEM SET UP
YES
SELECT PROBLEM MODE
SELE PRE PROGR LESS PLA
ENABLE REQUEST FOR POSITION INFORMATION
RECORDED PARAMETERS SATISFACTORY
NO
SELECT ADDITIONAL PARAMETERS
YES
PROGRAMMED MALFUNCTIONS SATISFACTORY
NO
SELECT REQUIRED MALFUNCTIONS
YES
PROBLEM PARAMETERS SATISFACT-ORY
NO
MODIFY PROBLEM PARAMETERS
YES
LESSON SATISFA
MODIFY ENVIRONM VARIABLE AIR TEMPE BAROMETR PRESSURE AND WIND
KOR AND CUEING SATIS.
NO
MODIFY KOR AND CUEING.
YES
PERFORMANCE MEASURES STORED FOR PRINTOUT
NO
REQUEST COMPUTER STORAGE OF MEASURES
YES
SURFACE RADIO FACILITIES AND PARAMETERS SATISFACT-ORY
NO
MODIFY RADIO FACILITIES
ASSIGN STUDENTS TO INSTRUCTORS AND TDOs
SELECT TAC MO SUB MOD (AOTS ARCS

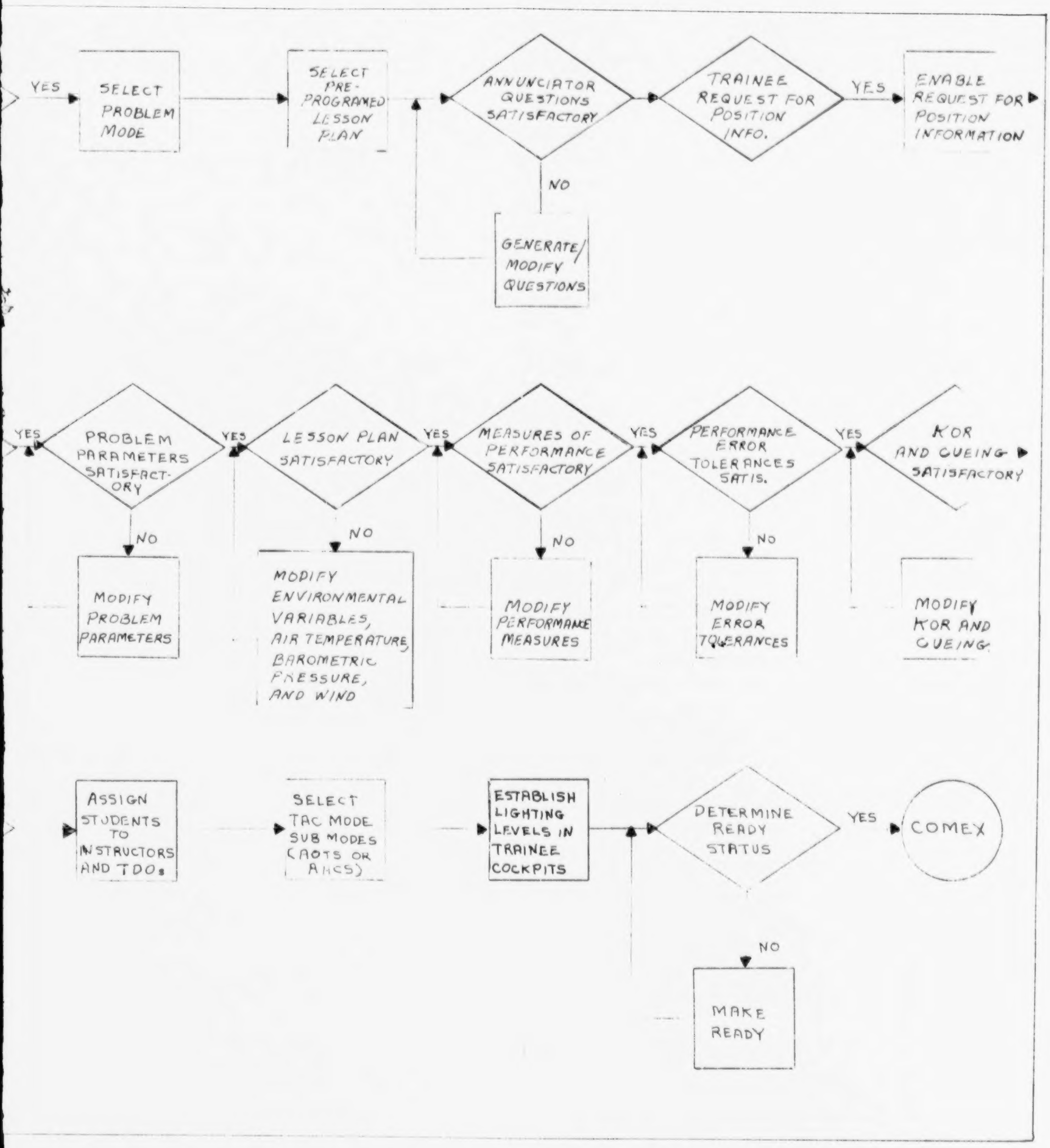

YES
SELECT PROBLEM MODE
SELECT PRE-PROGRAMED LESSON PLAN
ANNUNCIATOR QUESTIONS SATISFACTORY
NO
GENERATE/ MODIFY QUESTIONS
TRAINEE REQUEST FOR POSITION INFO.
YES
ENABLE REQUEST FOR POSITION INFORMATION
YES
PROBLEM PARAMETERS SATISFACTORY
NO
MODIFY PROBLEM PARAMETERS
YES
LESSON PLAN SATISFACTORY
NO
MODIFY ENVIRONMENTAL VARIABLES, AIR TEMPERATURE, BAROMETRIC PRESSURE, AND WIND
YES
MEASURES OF PERFORMANCE SATISFACTORY
NO
MODIFY PERFORMANCE MEASURES
YES
PERFORMANCE ERROR TOLERANCES SATIS.
NO
MODIFY ERROR TOLERANCES
YES
KOR AND CUEING SATISFACTORY
MODIFY KOR AND CUEING
ASSIGN STUDENTS TO INSTRUCTORS AND TDOs
SELECT TAC MODE SUB MODES (AOTS OR AHCS)
ESTABLISH LIGHTING LEVELS IN TRAINEE COCKPITS
DETERMINE READY STATUS
YES
COMEX
NO
MAKE READY

Figure 10. Instructor Premission Operations Envisaged for Device 1D23 Air Navigation Trainer.

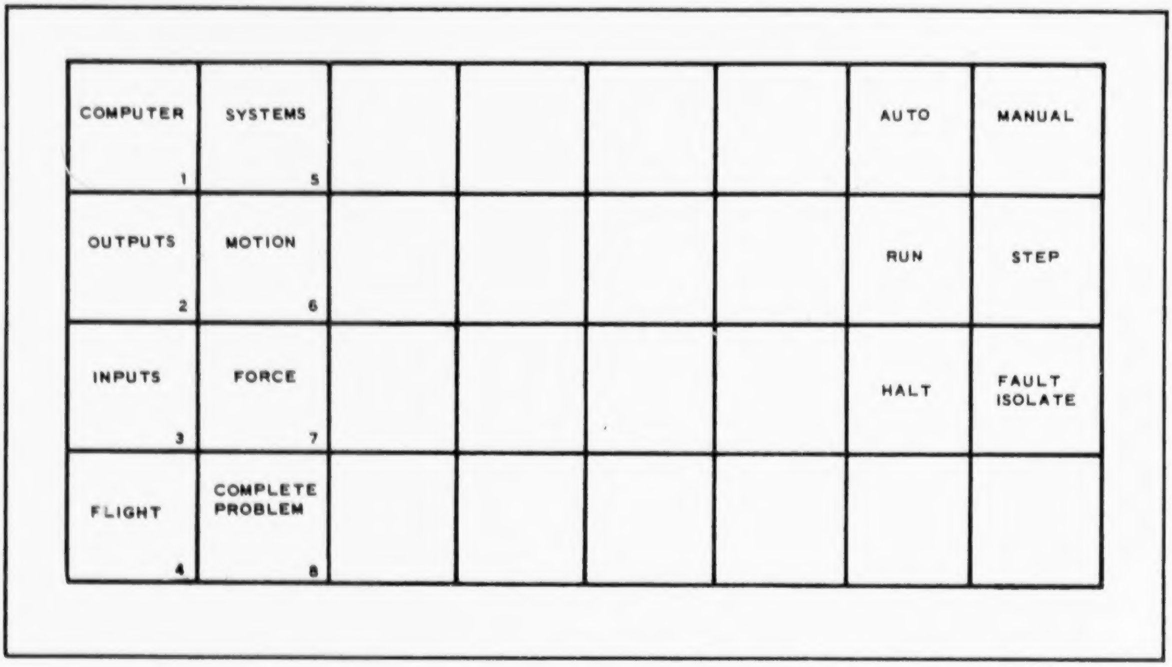


Figure 11. - DRED Mode Overlay
(from Goodyear 1971)

For existing scenarios, the design requirements include: means for mounting the preprogramed scenario for on-line use; a capability for reviewing scenario presentation in summary; and controls for initializing the trainer for mission operation.

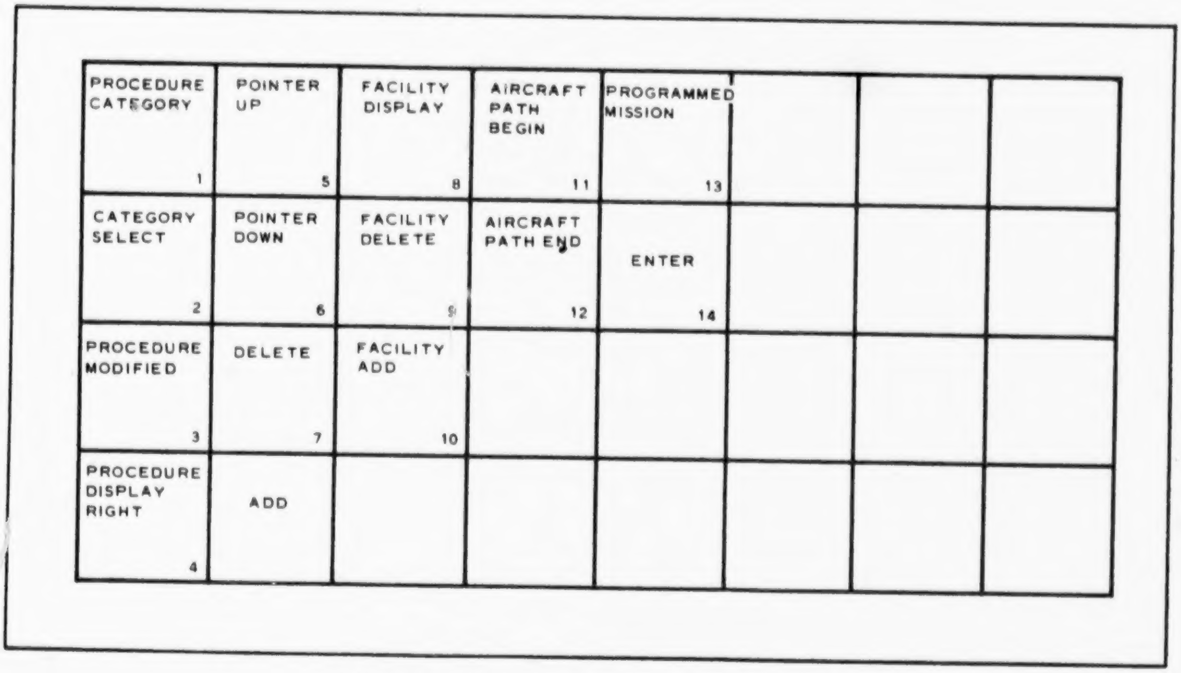
To modify existing scenarios for current use, means must be provided to alter lesson plan parameters or modify the processing flow. An example of this capability is provided in the specifications for device 2F101 (T-2C OFT) (NTDC 1971). The PLAN mode of operation enables the instructor to change the programed order of checklist procedures, alter programed mission legs or segments and delete or add to the surface facilities. A proposed PLAN mode overlay on the function keyboard used in conjunction with a light pen and CRT is shown in Figure 12 (Goodyear 1971). For example, the instructor is able to change a mission leg by rewriting the maneuver to be performed, the parameters to be monitored and the ending of the leg. To achieve this, the following steps are accomplished with the PLAN mode overlay.

- Depress PROGRAMED MISSION switch on the function keyboard.

- Display the legs to be changed by typing on the keyboard the programed mission number and the leg number for all the legs to be changed.

- Change the leg parameters by typing on the alphanumeric keyboard the programed mission number, the leg number, the maneuver to be performed, the mission leg end, and the parameters to be monitored.

- Depress ENTER switch on the function keyboard. The display of the legs to be changed and the typed alphanumeric information will be displayed on the CRT in the appropriate format.



PROCEDURE CATEGORY 1	POINTER UP 5	FACILITY DISPLAY 8	AIRCRAFT PATH BEGIN 11	PROGRAMMED MISSION 13			
CATEGORY SELECT 2	POINTER DOWN 6	FACILITY DELETE 9	AIRCRAFT PATH END 12	ENTER 14			
PROCEDURE MODIFIED 3	DELETE 7	FACILITY ADD 10					
PROCEDURE DISPLAY RIGHT 4	ADD						

Figure 12 - PLAN Mode Overlay

(from Goodyear 1971)

An example of an off-line editing capability for modifying an existing set of preprogramed problem parameters is provided by device 2B24. It represents a navigational aids editing sequence. The complete typewriter routine for making the desired navaids change is shown below.

```
NAV AIDS EDIT

STATION TYPE (UHF, FM, VHF, VOR, ADF, ILS, GCA)? VOR
WANT LIST OF CURRENT STATIONS? N
WANT TO EDIT? Y
WHAT LINE NUMBER? 2
2 SPARE
WANT CHANGE? Y
REPLACE/ADD/DELETE (R, A, D)?  A
INPUT  DHN
DONE? Y
WANT STATION PARAMETERS? Y
WHAT STATION NUMBER? 2

VOR      CALL      DHN

LNO1  FREQ
LNO2  XPOS
LNO3  YPOS
LNO4  RNGE
LNO5  ALT
LNO6  MV

WANT TO EDIT? Y
WHAT LINE NUMBER?  1
1  FREQ
WANT CHANGE?  Y
   WHAT VALUE?  111.6
DONE?  N
WHAT LINE NUMBER?  2
2  XPOS
WANT CHANGE?  16.85
DONE?  N
WHAT LINE NUMBER?  3
3  YPOS
WANT CHANGE?   -36.35
DONE?   N
```

```
WHAT LINE NUMBER?    4
4  RNGE
WANT CHANGE?    120
DONE?    N
WHAT LINE NUMBER?   5
5  ALT
WANT CHANGE?    400
DONE?    N
WHAT LINE NUMBER?    6
6  MV
WANT CHANGE?    2.2E
DONE?    Y
WANT NEW STATION NUMBER?  N
WANT NEW STATION TYPE?    N

   JOB DONE

EDIT COMPLETE-READY TO STORE DATA
```

3.4.1.3 Generation of New Scenarios. An off-line capability for instructor generation of new scenarios is required when appropriate existing preprogramed scenarios are unavailable. The information requirements pertinent to the design of software and hardware to accept, interpret, store and execute the instructional inputs include the following.

- Establish the exercise type and level of task difficulty (where the exercise belongs in the total training sequence) and identify the tasks, maneuvers and segments to be taught.
- Establish scenario structure ("problem world," facilities, vehicles, targets, media)
- Establish the parameters and their quantities/values (e.g., environmental conditions, flight paths, vehicle parameters, mission events, etc.)
- Identify the malfunctions to be incorporated, the insertion points and the probabilities of malfunction insertion in automatic modes
- Define the performance measures and enable the display and recording of all performance and error information available in the computer

- Specify the error criteria and tolerance envelopes for performance, and modifications in error criteria as a function of student performance

- Provide performance demonstrations and specify the replay rules and conditions

- Establish the guidance and feedback supports and the rules for student assistance (prompts, cues, knowledge of results)

- Provide automated aural briefings (as appropriate)

3.4.1.4 Readiness for On-Line Operations. Design must also make provisions for additional operations which occur just prior to initiation of an actual training exercise. This type of instructor control capability is exemplified in the following.

- In multi-student trainers involving a number of instructors, provide means for the assignment of selected students to given instructors

- In multi-student trainers, provide means for the selection (and indication) of trainee stations in "ready" status

- In general trainers, provide means for selecting the pertinent active mission displays and information inputs in the trainee station (e.g., displays and controls pertinent to a reconnaissance mission vs. a defensive mission in EW training).

3.4.2 TRAINING PROBLEM FORMULATION AND PRESENTATION.

Means must be provided for the installation of training content in the device. Instructor involvement centers about two basic design options: automated preprogramed lesson plans, or the manual setup of initial conditions for an exercise (including the capability for preprogramed initial condition data sets involving instructor selection of a given data set). The design issue concerns establishing the training problem parameters and the content of instruction for each exercise in a sequence of training.

3.4.2.1 **Preprogramed Training Exercises.** The human factors inputs include the specification of the content of the instructional sequence, the number of, and variations in the exercises and the grading of the content set on a continuum of problem difficulty ranging from basic indoctrination training objectives to advanced complex performance sequences. The stringency of the performance standards for the exercises is usually correlated with the difficulty continuum.

The information requirements that must be fulfilled to achieve a lesson plan library involve the following.

3.4.2.1.1 Job Content. The range of specific tasks and performance conditions that define the content of training must be defined. This considers the total task, mission segments or maneuvers that are to be installed for training. Two examples are provided here to indicate the information requirements pertinent to design. The first concerns the job content for the Air Navigation Trainer, Device 1D23 (NTDC 1971). The preprogramed lesson plans essentially call for a one-to-one correlation with the job of the navigator in the air environment. The exercises are constructed to enable the student to apply directly what he has learned and experienced in the device to realistic air navigation problems. The content centers on typical naval air operations involving basic air navigation, navigational systems operation, fuel management, and radio communications. The content range is identified below.

- Basic dead-reckoning navigation--This involves the utilization of VOR, ADF, TACAN, VORTAC, and doppler and inertial navigation aids. Emphasis is placed on basic enroute navigation procedures, navigational flights, calculations of wind effects, and fuel management (and includes relevant malfunctions in navigational equipments).

- Airways navigation--This involves low altitude (victor) and high altitude (jet) airways navigation. Job requirements include: general procedures in airways navigation; airways interceptions; position establishment via navaids (ADF, VOR TACAN); communications (IFR, VFR reports); fuel management (including bingo time, fuel and distance), ETA and weather problems; and critical enroute problems (e.g., airspace violations resulting from drops in barometric pressure, jet stream variations, etc.).

- Operational navigation missions-- Typical operational missions are installed including: a bombing sortie involving segments of catapult launch, proceed to rendezvous point. engage target, return to carrier and carrier controlled approach; and a standard bombing sortie but with a scenario wherein the carrier is gone when the aircraft returns, requiring a search for the carrier (search time dependent on fuel remaining) and proceeding to the divert field and landing. Training objectives include: position determinations (via doppler/ inertial systems), fuel management, ETA, communications, and various system malfunctions inserted as required.

The second example illustrative of the information requirements for preprogramed training exercises is provided by the Synthetic Flight Training System, Device 2B24 (NTDC 1968). A series of exercises for training in instrument flight is provided; each exercise is made up of fifty contiguous problem segments. The student is required to perform the range of instrument flight maneuvers during the total training program. Each problem segment consists of a steady state condition and the transition from it to another steady state condition. It begins with a set of initial conditions and sufficient additional data to describe ideal performance during the exercise on such performance parameters as airspeed, altitude, flight path, rater of climb, rate of turn, bank and pitch altitude, and on engine parameters. Malfunctions (e.g., in electrical system, engine system, flight control system) are included in the programed scenarios.

3.4.2.1.2 Organization of Exercises. Once the content is determined, the exercises are organized individually and across the sequence of training to provide a coherent program of instruction. In devices which provide a direct transfer of training to the operational counterpart, individual exercises are organized according to the relevant mission profiles or scenarios. In generalized or part task devices, exercises are organized in terms of the functions defined in the training objectives.

The number of exercises required to achieve the desired library is specified. This includes the range of different exercises desired as well as the variations on each theme.

3.4.2.1.3 Problem Difficulty. A key feature in training content development is the organization of exercises in a manner most advantageous to the shaping of student behaviors. The most useful scheme is to provide a defined series of exercises graduated on a continuum of difficulty. This is achieved in one or a combination of ways, depending on the nature of the device and on the instructional requirements.

- Easy to hard continuum--This organization is based on the nature of the task and on a continual increase in the events provided in training (and, therefore, on the demands placed on the student). Involved is a logical progression of training content from simple to increasingly more difficult sequences of performance. For example, in Device 1D23, the progression of instruction begins with indoctrination exercises and continues with basic dead-reckoning navigation, and ends with navigation exercises in representative operational mission contexts.

- Procedural to fully integrated continuum--This difficulty dimension is reflected in an exercise series wherein initial exercises are concerned with procedural adequacy. From this, more complex training objectives are installed (in which previously accomplished objectives are included in that they represent building blocks for more complex activities). Thus, later exercises emphasize full utilization of the portions of the system trained in earlier exercises.

- Conditions of performance--Task difficulty may also be manipulated by providing increasingly stringent conditions on performance. The classes involved here include: the speeds of event happenings (e.g., faster own-ship and target speeds), environment degradation (e.g., variable winds and speeds, variability in water conditions), and stimulus degradation (e.g., intermittent targets, garbled communications).

- Error tolerances--Task difficulty may be increased, all other things equal, by imposing increasingly stringent error requirements on adequate performance, as a function of stage of training(e.g., precision demanded in manual control responses).

- Stimulus supports--Similar task sets may be varied in difficulty as a function of the amount of stimulus supports built into an exercise (e.g., prompts, cues, knowledge of results, stimulus enhancement).

- In some situations a graduated difficulty continuum is not an issue. The requirement is to provide exposure to a range of events and happenings which occur in the operational counterpart. This recognizes that the ordering of materials is as important as the difficulty progression in learning. Certain job situations involve the acquisition of a set of skills before additional skills can be mastered and these may be no more difficult than the preceding set. This is particularly so in cognitive tasks and in verbal learning. The familiar part-task to whole-task learning progression is meaningful here. Thus, this approach favors situations where subtasks are progressively added to the learning situation so that the amount of information learned increases as a prelude to handling other aspects of the job. The human factors requirement is to specify the range of these events so that they may be simulated in the appropriate instructional contexts (i.e., coverage of all relevant events).

3.4.2.1.4 Performance Standards. The standard of adequate performance and the error tolerances for each exercise must be stipulated (this is discussed in paragraph 3.4.7.3 in the chapter on Measurement System Design).

3.4.2.1.5 Scenario Modification. Means must be provided for 1) off-line generation or modification of scenarios, and 2) on-line intercession into the preprogramed scenario to provide the flexibility to develop an instructional strategy tailored to, or at least pertinent to each student.

3.4.2.2 Manual Installation of Initial Conditions. Insertion of problem parameters to the simulation program is made at the instructor console when preprogramed exercises are not warranted. This may be accomplished via individual controls for setting up the desired initial conditions, or via the selection of a preprogramed initial conditions data set. An example of each is described next.

The ASROC/ASW Early Attack Weapon System Trainer, Device 14A2 (NTDC 1964) provides for the individual parameter setup of the initial conditions for each exercise. The classes of controllable parameters that are installed at the instructor console are the following:

- Own-ship
  course
  speed
  position (XY)
  equipment malfunction

- Support units
  range
  bearing
  course
  speed
  altitude (aircraft)

- Target
  position (including contact at prescribed time)
  range
  bearing
  course
  speed
  depth
  type submarine (via speed)
  aspect
  doppler
  false target

- Environment
  sea state
  layer depth
  wind

- Weapons
  ASROC
  DASH
  AWTT
  nuclear depth charge
  aircraft torpedoes
  submarine torpedoes

These manipulables are employed, as required, in a series of training exercises graduated in difficulty. Three groupings (blocks) of training exercises are utilized. The first block centers on basic attack procedures (non-mission context) in which the objectives specify the development of fire control solutions and launch procedures for the relevant weapons. The next block of objectives is devoted to single ship sequences in the screen mission context where the previous block requirements are imbedded in a total mission from search and detection through weapon assignment and target prosecution. The final block deals with multi-unit missions (Search and Attack Unit (SAU) context) involving more complex tasks of coordinating the operations of other units. This represents the fullest expression of coordinated team training objectives.

The A-7E Operational Flight Trainer, Device 2F100, provides for instructor selection of preprogramed sets of initial conditions. At least ten of these preselected data sets are stored in computer memory and are addressable at the instructor console. In addition, the capability is provided to permit the instructor to change the values of these data sets. Verification of the existing content is also provided via a hard copy print-out of initial condition data.

The preprogramed initial conditions data sets include the following:

- aircraft position coordinates
- altitude
- velocity
- heading
- attitude
- fuel
- oxygen
- weather conditions and aircraft environment (wind, barometric pressure, rough air, icing, magnetic variation)
- radio aids changes program (select station number, type, parameter and data)

- chart changes program (select appropriate chart and parameters)
- recorder modes selection (mode of operation, approach station and approach parameters)
- takeoff and landing simulation program (catapult takeoff, normal takeoff, arrested landing, normal landing)
- also, preprogramed values are inserted for computer control of parameter deviation (for automatic performance recording systems).

3.4.1.3 Pre-exercise Briefing. The automated briefing of students, while in position in the trainee station, is a desirable option to accompany preprogramed training and evaluation (e.g., checkride) mission scenarios. An automated library of briefing materials and control signals for demonstrations (e.g., tape cartridges) properly loaded and indexed to correct start points is the design goal. The selection of the briefing events depends on the purpose of the training exercise and on the level of learning the student is at (exercise number in the total sequence of learning).

The information requirements for achieving this capability include the following:

a) The purpose and scope of the training (or evaluation) exercise, including a description of the mission profile and the procedures involved (problem content).

b) Articulation of the training objectives

  - performance elements--e.g., catapult launch; search and attack options; heavyweight takeoff; weapon actions, communications-navigation requirements such as required in instrument flight operations; etc.
  - conditions of performance--environmental conditions; emergencies and malfunctions; partial panel (flight) operations; aircraft configuration.
  - measurement--emphasis on what will be scored or what is required in performance; indication of automated adaptive scoring (if applicable).

- performance criteria--indication of what is expected and the error tolerances for successful performance in the specified exercise.

c) Guidance and instructional supports provided

- demonstration capability provided (based on the description of the lesson and what is expected of the student).

- student capability for direct request for assistance, e.g., request for position (lat/long) information; reduction in task difficulty (e.g., freezing a control parameter, such as holding altitude constant in flight).

- capability for reinstruction on scenario aspects performed below expected tolerance limits

- capability for student control of instruction (student-paced instruction)--the instructional options provided the student are selected from the following:

  - freeze/unfreeze the trainer

  - initiate/terminate preprogramed demonstrations in real/slow time

  - select or initiate training exercises or segments of an exercise

  - platform motion system on/off

  - select displays of performance as appropriate (e.g., error display)

  - modify exercise difficulty by disabling an external forcing function (e.g., turbulence) or disabling a vehicle characteristic in order to simplify the control task (e.g., select a constant altitude in order to concentrate on heading control)

  - reset the trainer to the programed initial conditions for the exercise

d) Support material provided--the materials pertinent to the given exercise are made available to the student (e.g., route maps, radio facilities and ground stations and their frequencies, doctrinal publications such as ATP-1, etc.).

e) Communications capability between student and instructor.

3.4.3 DATA HANDLING AND DISPLAY

The instructor station display system must provide complete training data on all students during an exercise and enable the monitor and control of the pertinent aspects of performance. This is a crucial aspect of design, for the effectiveness of the instructional system is predicated on this capability. The complexities in providing effective data handling and display requires considerable human factors effort in determining the information requirements for design.

The human factors inputs to the technical approach determination are influenced by a series of criteria which must be tacitly assumed in deriving the information requirements for design. These criteria concern:

- Display flexibility to call up any relevant aspect of student performance or problem feature on demand, with no detrimental lags in information presentation.
    - mission/geographic areas
    - scale variations
    - information classes
    - display modes
    - coding of displayed information.
- Adequate update of performance information.
- Uniformity of information display in characters/symbols in multi-format contexts.
- Commonality of data locations in multi-format contexts.
- Information-handling capability (amount, types, rapidity of change, number of students under control).
- Multi-format requirements, high density information display, information integration (alpha-numeric and situational/graphic display requirements involving discrete event and overall situation displays; continuous alpha-numeric error readouts).
- Rapid mode changes for monitoring, control and evaluation, requirements for monitor and control of more than one student sequentially.
- Accuracy, reliability and registration (information alignment) of the visual displays.

- Expansion capability (for future display requirements).
- Visual factors
  - legibility
  - refresh rate
  - contrast sensitivity
  - resolution
  - clutter

The cathode ray tube display (with appropriate accessing controls) is the most efficient means for satisfying the design criteria. The CRT system utilizes the computer to present and update the classes of information required at given times in the exercise. This type of display is capable of presenting all of the critical training information, as required, in a small viewing area. In short, the CRT is able to provide more understandable and instructionally meaningful information in the shortest time period than any other display means. It is for these reasons that the discussion on the information requirements for data handling and display centers on the CRT system. No material is provided in this chapter on other types of information displays which are also involved in instructor station operations.

The information requirements must consider a variety of design features, notably the display modes and locations, visual factors, information formatting requirements and the precision of the displayed information. Accordingly, the discussion considers the following categories:

- display content and formatting requirements
- visual factors in design
- specific display requirements
- controls for display selection and modification

3.4.3.1 Display Content and Formatting Requirements. The display information must provide sufficient content and organization to enable the capability for monitoring and evaluating all critical aspects of the mission cycle or lesson plan and for modifying the training environment to shape student behaviors commensurate with demonstrated performance. Unfortunately, the information requirements for design cannot be specified in a straightforward manner because of the diversity in content requirements not only across classes of training devices but also in terms of the specifics relative to given trainers within a class.

Accordingly, to provide useful guidelines for design, the approach elected is to restrict this chapter to provide: 1) only information that has some commonality to a number of display situations, and 2) display examples representative of a range of situations of interest to the human factors specialist.

All pertinent aspects of student performance and system status must be available for display either continuously or on demand. This involves the display of performance and status information in all operating modes for the specific trainer, both on-line and off-line. Of concern are the various modes of trainer operation for monitoring and evaluating student performance during an exercise (see Paragraph 3.4.6.1) and the display modes required for off-line operations. The off-line operations, only identified here, include the following modes:

- daily readiness mode--capability to monitor and control the daily checkout of the trainer (see Chapter 3.4.1).
- problem setup mode--capability for generating preprogramed lesson plans or modifying existing ones, and selecting lesson plans for the training exercise (see Chapter 3.4.1).
- inspect and change mode--capability to inspect and change the library of instructor-controlled parameters in the preprogramed lesson plans (see Chapter 3.4.1).
- replay mode--capability to replay the training mission in real-time for performance critique and in fast-time for search and freeze.

3.4.3.1.1 Display Requirements. During the exercise (enroute) a variety of displayed information is required to support the instructional decisions and actions. The following determinations must be made to achieve the display content and flexibility in data presentation:

- display format for each mode--This involves the grouping and positioning of the displayed information with an emphasis on commonality in format and data positioning across the modes.
- type of display--Both graphic and alphanumeric information and combinations of both are required.
- events to portray per display--This refers to the range of events pertinent to the device under consideration and includes such groupings as error classes, students who exceed preset tolerances, flight track and performance information on all students, etc.
- CRT page formats--This includes the presentation of sequential data in successive pages or independent pages of data.

- the data common to each display mode must be identified; uniformity of information display categories in multi-format situations is required to avoid ambiguity and clutter and to minimize search time.

- size of the mission area--This refers to geographic scale and the capability to select desired scales.

- continuous display of information vs. on-demand presentations.

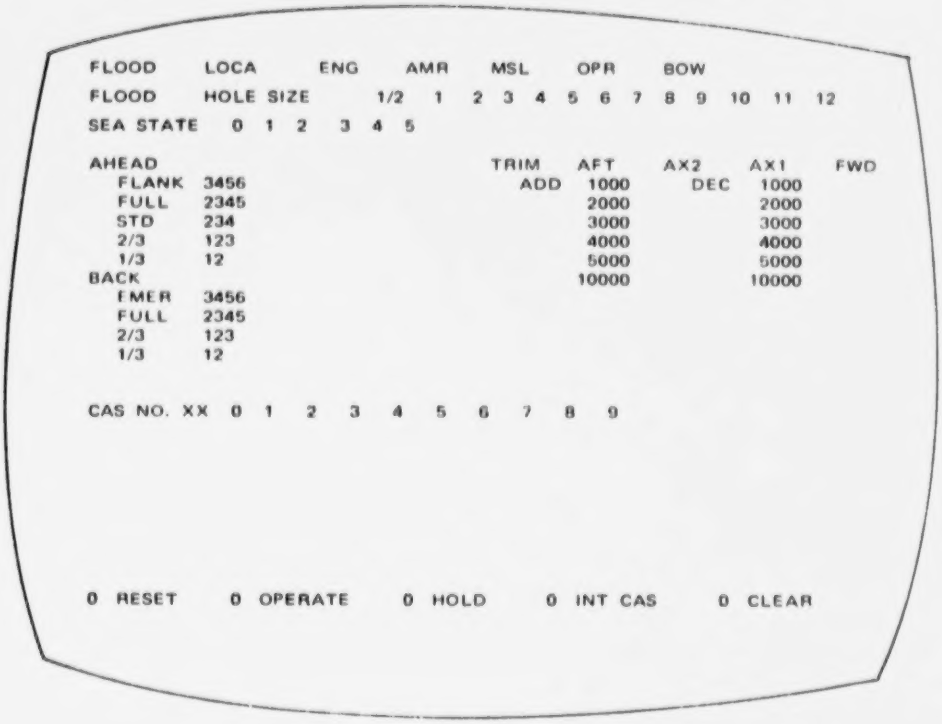
- specific information--This refers to the display of information specific to the environment represented in the trainer (e.g., classes of EW emitters radiating, aircraft under control, etc.), and to stylized information for depicting defined relations (e.g., bargraphs, performance data displays, etc.).

The display of student performance and system status information needed to maintain instructional control and to develop training strategies is as varied as the training devices currently on-line or in development. However, the various CRT display requirements may be organized in terms of the information needed in monitoring, evaluating and controlling performance and in the instructional functions performed during an exercise. These features must be clearly defined prior to deriving the display contents and formats and to determining what information is continuously displayed, or selected on demand. Determining the content and organization of the displayed information must be anchored to the following instructional capabilities (as appropriate). Within these capabilities, guidelines for design are provided through the use of selected CRT display examples which indicate the range of the content displayed and the alphanumeric and pictorial formatting arrangements.

- display of initial conditions at problem start--Figure 13 shows an alphanumeric format of a typical initial conditions display for a generalized submarine advanced casualty ship control trainer (Lamb, Bertsche and Carey 1970).

- demonstration mode.

- monitoring and control of events throughout the exercise--Figure 14 provides a display of flight track information on all students for an air navigation trainer (Bark, et al, 1969). A combined graphic and alphanumeric format is proposed. An example of a stylized display for monitoring frequency



```
FLOOD      LOCA       ENG       AMR       MSL       OPR       BOW
FLOOD      HOLE SIZE        1/2    1    2  3  4  5  6  7  8  9   10   11   12
SEA STATE    0  1  2   3  4  5

AHEAD                                   TRIM     AFT      AX2      AX1      FWD
   FLANK  3456                              ADD  1000         DEC  1000
   FULL   2345                                   2000              2000
   STD    234                                    3000              3000
   2/3    123                                    4000              4000
   1/3    12                                     5000              5000
BACK                                             10000             10000
   EMER   3456
   FULL   2345
   2/3    123
   1/3    12

CAS NO. XX  0   1   2   3   4   5   6   7   8   9




0  RESET     0  OPERATE     0  HOLD     0  INT CAS     0  CLEAR
```

Figure 13. Initial Conditions Display for Submarine Advanced Casualty Ship Control Trainer. (from Lamb, Bertsche and Carey 1970)

coverage in an Airborne Electronic Warfare trainer is shown in Figure 15. In the monitoring mode the instructor may interrogate the computer via lightpen to determine the performance and mission status of each student irrespective of specific errors made.

- reinstruction mode (see Paragraph 3.4.6.2.2).
- event insertion--displays are required to provide information to assist in determinations of whether to insert additional events or delete programed events in a preprogramed scenario, based on student performance. Figure 16 depicts the airborne intercept mode for the Electronic Warfare trainer cited above. Two approaches may be employed for displaying preprogramed airborne interceptor aircraft (A/I). In the first instance,

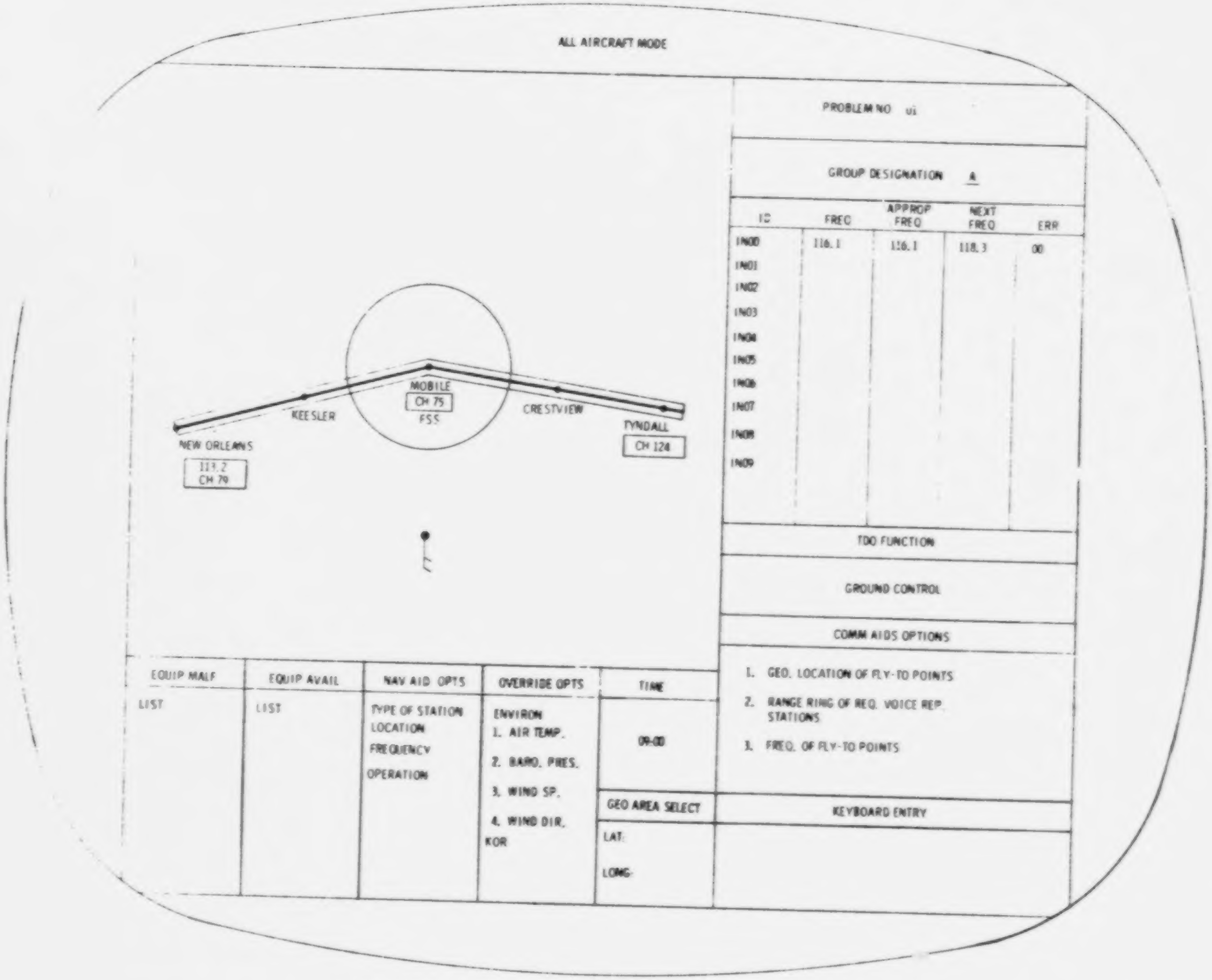


Figure 14. Combined Graphic and Alphanumeric CRT Format.

(from Bark, et al 1969)

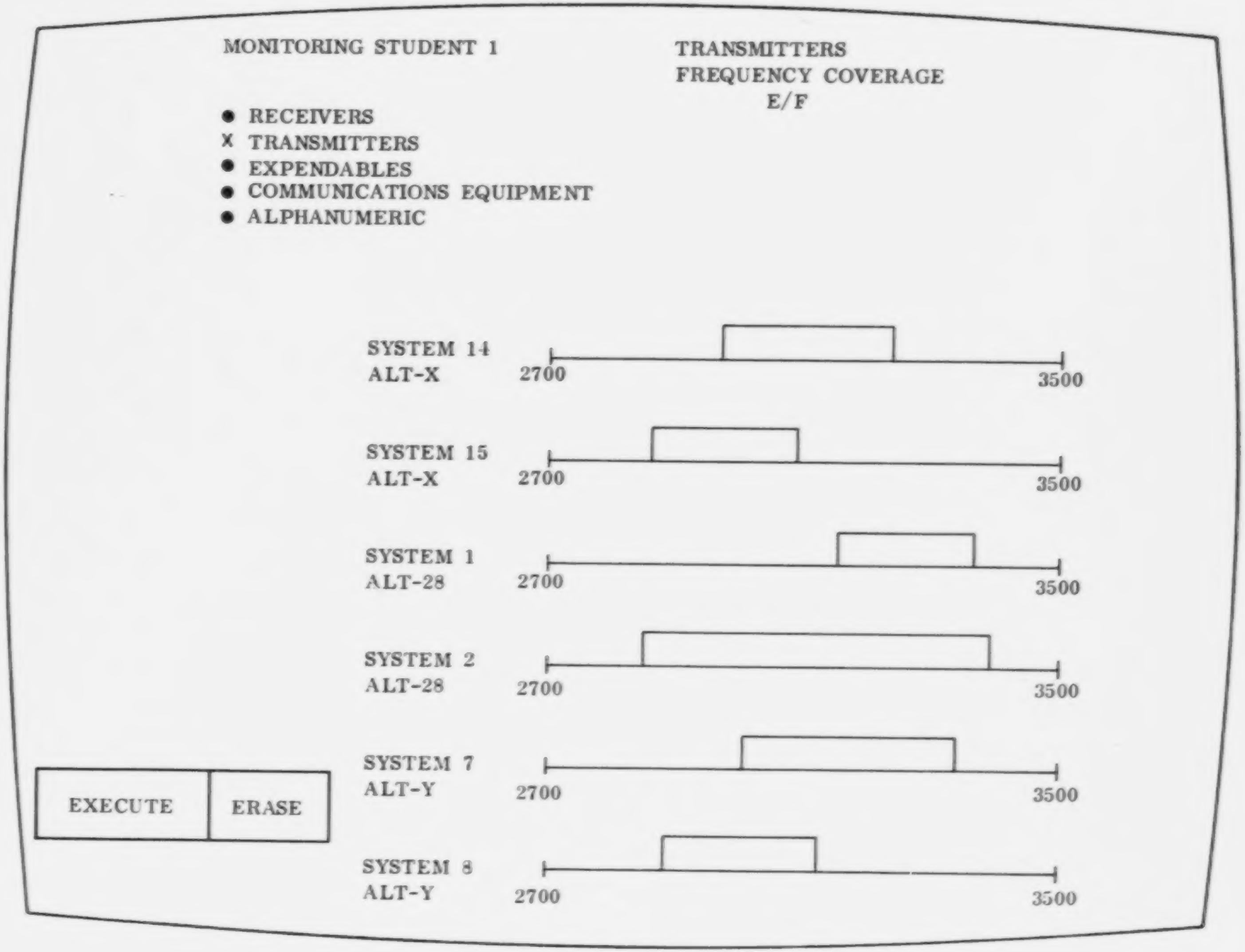


Figure 15. CRT Page Format for Monitoring Frequency Coverage.

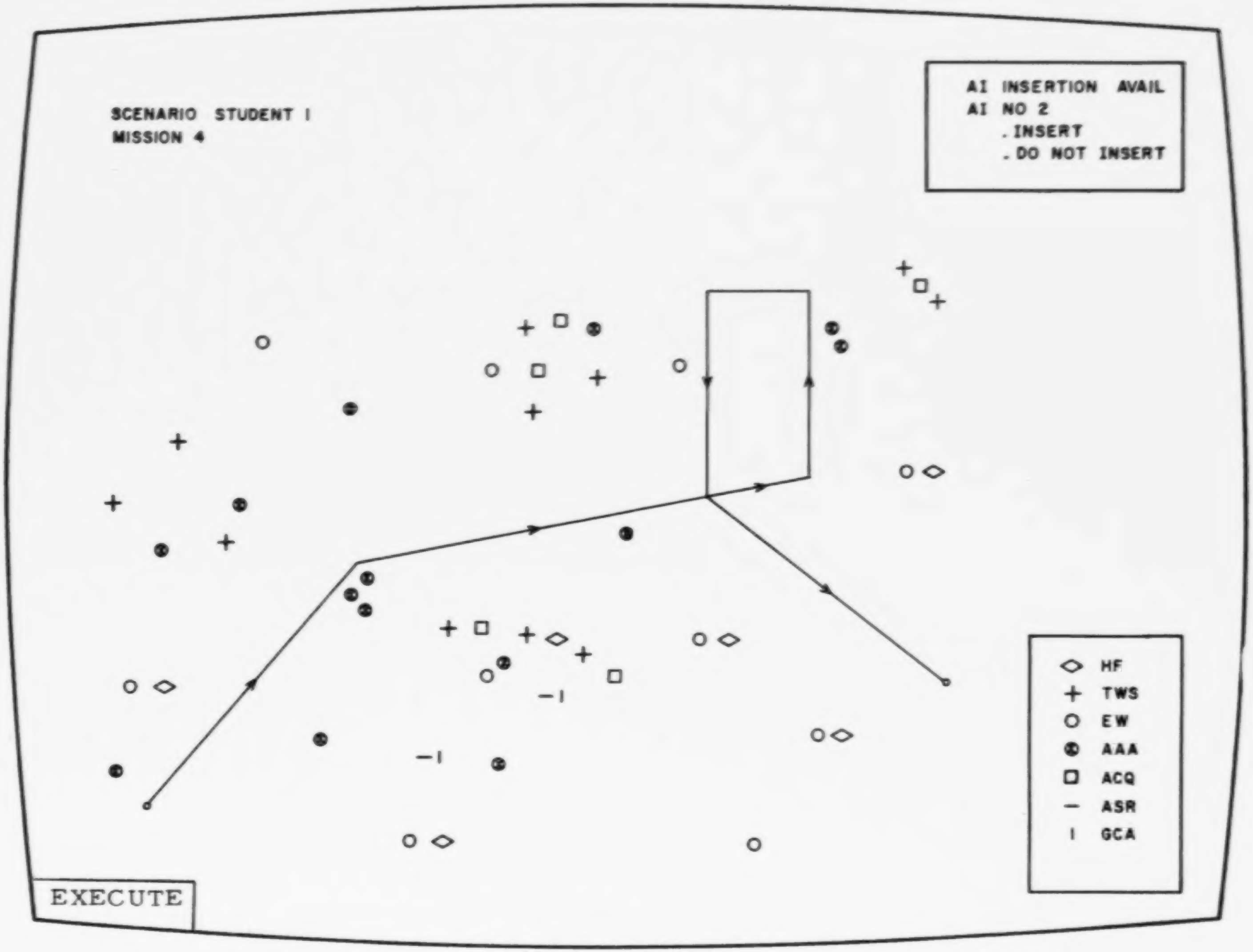


Figure 16. EW Mission Scenario With Airborne Interceptor Control Capability.

a programed A/I will come on unless overridden; this is accomplished by the placement of the lightpen on DO NOT INSERT and EXECUTE. In the second instance, to insert a non-programed A/I into the problem, the lightpen is placed on INSERT and EXECUTE. The CRT display is an example of a pictorial format.

- error alert mode (see Paragraphs 3.4.6.4.1 and 3.4.7.5.1).
- performance assessment--A variety of formats are required to obtain performance and error production information. Figure 17 provides a display of performance data for a submarine advanced casualty ship control trainer. This display graphically shows the response of the ship to various casualty and recovery actions. It may also be used for debriefing the student on the outcomes of performance. Two forms of error production information are depicted. Figure 18 provides a continuous presentation of critical student errors, accrued throughout a mission. The example is from the above-cited Airborne Electronic Warfare trainer. Nineteen error classes are identified for display. The error groupings common to the basic reconnaissance and defensive missions in the mission profile are:

  - switch setup positions
  - equipment preset (bands/frequencies requirements)
  - switch setup for signal analysis
  - threat priority
  - evasive maneuvers
  - communications
  - switch shutdown positions

  The error groupings pertinent to the basic defensive mission are:

  - threat assessment
  - switch setup for jamming
  - initiation for jamming
  - use of expendables
  - environment coverage

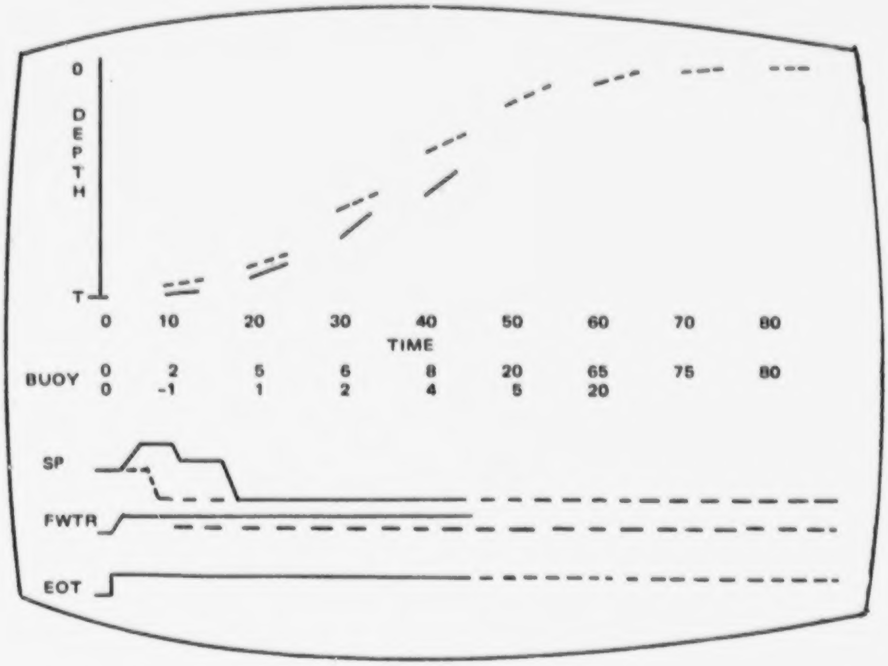
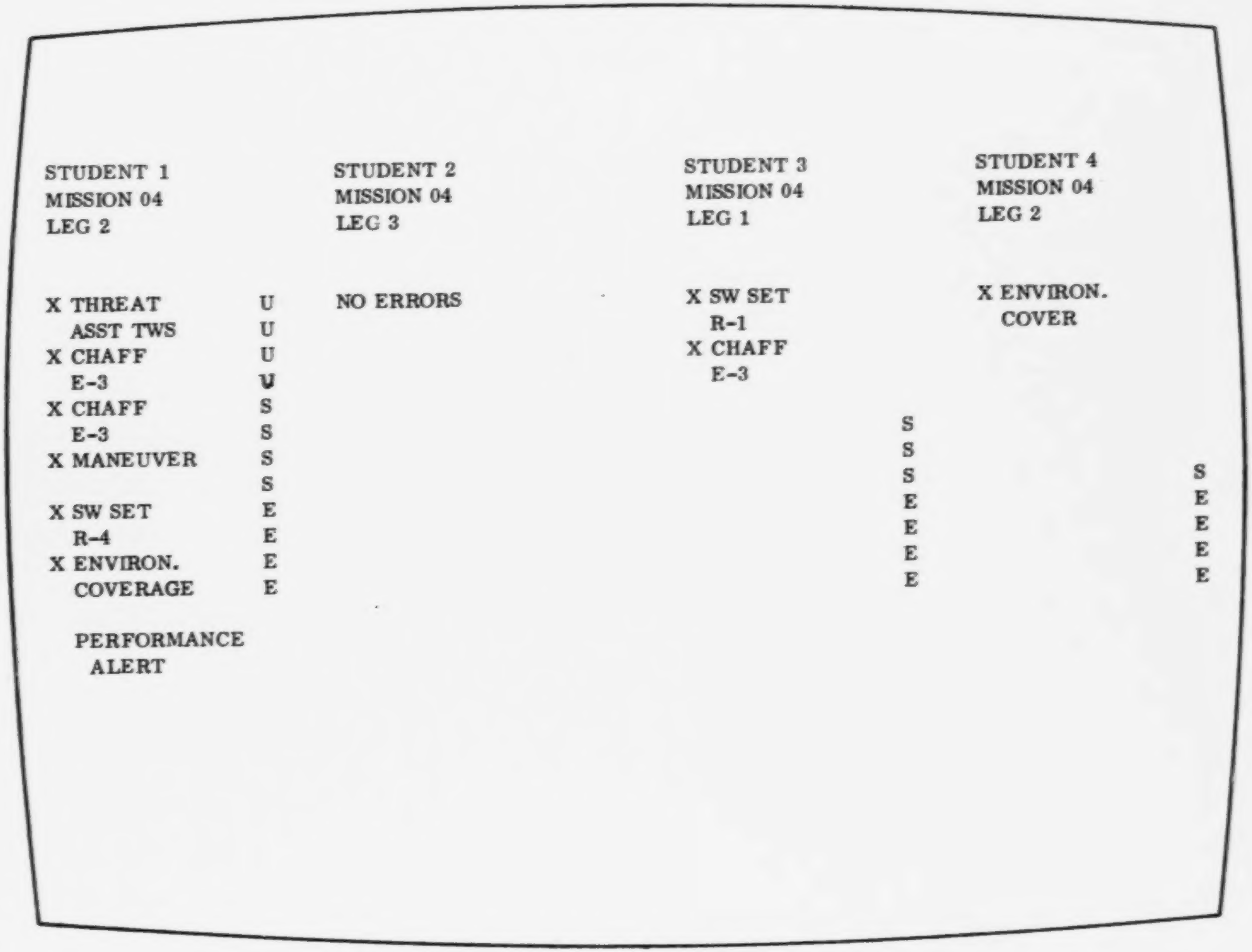


Figure 17. Performance Data Display.
(from Lamb, Bertsche and Carey 1970)

The error groupings pertinent to the basic reconnaissance mission are:

- signal setup for DF bearing
- recording
- analysis
- subsequent DF bearing
- priority search
- general area reconnaissance
- malfunction detection/correction

The alphanumeric display always shows the six most recent classes of error made by a student. Each error class is allotted 2 lines on the CRT. Additionally, throughout the mission, a bargraph denotes the level



```
STUDENT 1                 STUDENT 2              STUDENT 3                STUDENT 4
MISSION 04                MISSION 04             MISSION 04               MISSION 04
LEG 2                     LEG 3                  LEG 1                    LEG 2

X THREAT          U       NO ERRORS              X SW SET                 X ENVIRON.
  ASST TWS        U                                R-1                      COVER
X CHAFF           U                              X CHAFF
  E-3             U                                E-3
X CHAFF           S                                              S
  E-3             S                                              S
X MANEUVER        S                                              S                  S
                  S                                              E                  E
X SW SET          E                                              E                  E
  R-4             E                                              E                  E
X ENVIRON.        E                                              E                  E
  COVERAGE        E

  PERFORMANCE
    ALERT
```

Figure 18. Alphanumeric CRT Display Information Format.

of proficiency per student (Excellent, Satisfactory, Unsatisfactory) and an error alert indication (when applicable) which notifies the instructor that the student has almost achieved the limit of error (that is, error limit minus one error) and that a computer freeze of the mission will occur when another error of the same class is made. Also, information designating the student number, mission number, and leg number is displayed continually. The second example is shown in Figure 19 which presents a page format for error analysis per student for the setup of switches in the same Airborne Electronic Warfare trainer.

- malfunction mode--Figure 20 presents a display of casualties appropriate to the submarine advanced casualty ship control trainer. The instructor is able to initiate individual casualties from this array and the pertinent actions and outcomes are displayed on the CRT.

3.4.3.2 Visual Factors in Design. The specification of the CRT display requirements must also consider the visual factors which influence design. A sizeable number of visual issues are involved in equipment design (e.g., legibility, system resolution, brightness and contrast requirements, ambient illumination, flicker, etc.). These elements are interdependent, resulting in significant interaction effects, for example, the minimum visual angle for character legibility increases as contrast decreases. An indication of some of the possible parametric interactions among the visual factors is shown in Table 9 (Semple, et al 1971). While not complete, the table serves to highlight the complexities involved in display system design.

The information requirements for instructor station CRT display systems must consider a number of performance characteristics. These characteristics with recommended guidelines are outlined below. (The values provided represent current NTDC specifications.)

Performance Characteristic	Recommended Value
Minimum display refresh rate	30 frames/second (not interrupted by computer updating of display data)
Minimum display update rate	2 times/second (not affected by command inputs)

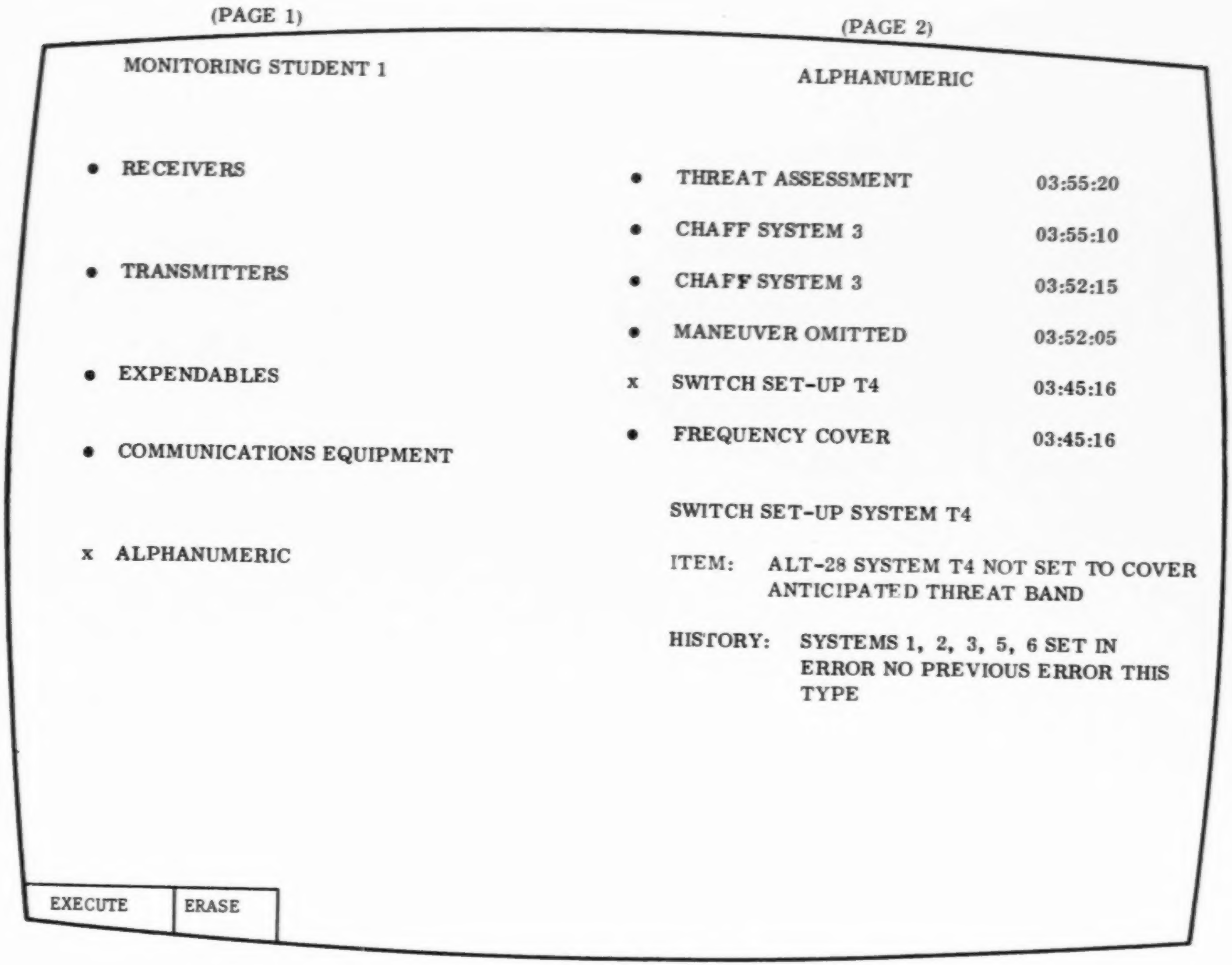
Performance Characteristic	Recommended Value
Minimum screen highlight luminance	20 footlamberts
Minimum small character height	0.15 inches
Minimum large character height	1.5 times small character height
Minimum horizontal raster lines per character height if raster scan is used	9 lines
Character width to height ratio	1:1.5
Minimum small characters per horizontal line including spacing	80
Minimum lines of characters per display page	60
Minimum number of intensity control levels excluding off	2
Display type	Rectangular type vertically aligned CRT with rectangular display border mask
Minimum usable horizontal display size	12 inches
Minimum usable vertical display size	16 inches
Minimum horizontal address resolution	1/750 (linear spacing)
Minimum vertical address resolution	1/1000 (linear spacing)
Accuracy	Within 2% of screen horizontal and vertical dimensions
Drift	Within 0.5% of screen horizontal and vertical dimensions over a period of eight hours with a ±50° fahrenheit temperature variation

Performance Characteristic	Recommended Value
Spot size	Less than 0.02 inches over the entire visible display area including the effect of jitter at a screen highlight luminance of 20 footlamberts
Character repertoire	At least 26 upper case alphabet, 10 numeric, and 26 other special characters
Lines and circles	Dot, dash, dot-dash, and solid line, all hardware implemented
Flashing rate	Once/second
Flashing on/off ratio	1:1
Maximum time from display request to display of requested data	3 seconds
Polarity switch	If raster scan is used, a polarity switch will provide a positive (dark characters on a light background) or a negative (light characters on a dark background) display.

For our purpose, the information requirements for CRT display design center on those performance characteristics which influence legibility and the speed and flexibility in adjusting display content. The relevant display elements are described next.

3.4.3.2.1 Legibility Requirements. A number of visual factors are subsumed under CRT display legibility. Those of importance in instructor station design are outlined below. Within each of the factors identified, some basic guidelines are provided for establishing the information requirements for engineering design.

- Viewing distance--The convention is to accept the maximum viewing distance (seated man) as 28 inches for operations normal to the line-of-sight. The minimum viewing distance from the eye to the display should not be less than 1-1/2 times the width of the display surface.



MONITORING STUDENT 1

● RECEIVERS

● TRANSMITTERS

● EXPENDABLES

● COMMUNICATIONS EQUIPMENT

x ALPHANUMERIC

ALPHANUMERIC

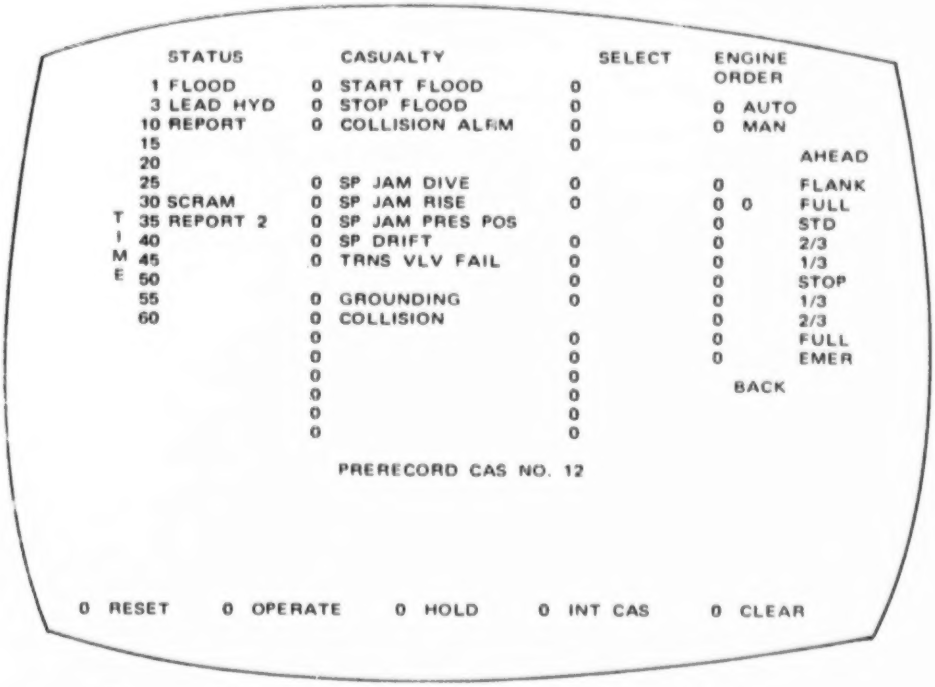
●	THREAT ASSESSMENT	03:55:20
●	CHAFF SYSTEM 3	03:55:10
●	CHAFF SYSTEM 3	03:52:15
●	MANEUVER OMITTED	03:52:05
x	SWITCH SET-UP T4	03:45:16
●	FREQUENCY COVER	03:45:16

SWITCH SET-UP SYSTEM T4

ITEM: ALT-28 SYSTEM T4 NOT SET TO COVER ANTICIPATED THREAT BAND

HISTORY: SYSTEMS 1, 2, 3, 5, 6 SET IN ERROR NO PREVIOUS ERROR THIS TYPE

Figure 19. CRT Page Format for Error Analysis, Switch Setup.



```
         STATUS          CASUALTY                 SELECT     ENGINE
       1 FLOOD         0 START FLOOD          0              ORDER
       3 LEAD HYD      0 STOP FLOOD           0              0  AUTO
      10 REPORT        0 COLLISION ALRM       0              0  MAN
      15                                      0
      20                                                             AHEAD
      25               0 SP JAM DIVE          0              0       FLANK
      30 SCRAM         0 SP JAM RISE          0              0  0    FULL
  T   35 REPORT 2      0 SP JAM PRES POS                     0       STD
  I   40               0 SP DRIFT             0              0       2/3
  M   45               0 TRNS VLV FAIL        0              0       1/3
  E   50                                      0              0       STOP
      55               0 GROUNDING            0              0       1/3
      60               0 COLLISION            0              0       2/3
                       0                      0              0       FULL
                       0                      0              0       EMER
                       0                      0                 BACK
                       0                      0
                       0                      0
                       0                      0

                         PRERECORD CAS NO. 12

 0 RESET     0 OPERATE     0 HOLD     0 INT CAS     0 CLEAR
```

Figure 20. Casualty Display for Submarine Advanced Casualty Ship Control Trainer.
(from Lamb, Bertsche and Carey 1970)

- Viewing angle--The optimum viewing angle is 90°; it should not be less than 45° and preferably at least 60° in the horizontal plane. The location of displays above the horizontal line-of-sight should not exceed 45°, however, no more than 15° is desired since head movement is restricted in this plane and fatigue is likely with continuous viewing.

- Visual angle--A practical standard is for the stroke width of display characters to subtend a visual angle of not less than 2 minutes. Evidence indicates that characters are most legible when the ratio of character height to stroke width is between 5:1 and 7:1. A simulator manufacturer (Singer-General Precision 1969) has determined character size by the formula:

$$\text{Character size (inches)} = \frac{\text{Viewing distance (inches)} \times \text{Visual angle (minutes)}}{3438.0}$$

TABLE 9. SUMMARY OF EYE-EQUIPMENT SYSTEM PARAMETER INTERACTIONS.

Eye Limitations	Equip. Resol.	Bandwidth	Scan Lines/Ht.	Spot Size	Display Size	Image Motion	Target Bright.	Background Bri.	Image Enhance.	Color	Wavelengths	Beam Intensity	Voltages	Spot Location	Phosphor Charac.	Screen Effec.	Faceplate	Halation	Deflection	"Granularity"	Bright vs. Dark Target	Vibration	MTF	Line Spread	Spot Spread	Amount of Info.
Visual Acuity	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Retinal Area Stim.	*		*	*	*	*	*	*		*	*	*	*	*				*	*		*	*		*	*	
Display Location	*				*				*					*		*	*									*
Cueing	*				*	*	*	*	*	*											*	*				
Target Contrast	*	*	*		*	*	*	*	*	*		*	*	*	*	*	*	*	*		*	*		*	*	
Ambient Illumination	*			*	*		*	*	*		*	*	*	*	*	*	*	*	*		*			*		
Background Illumination	*						*		*		*	*	*		*	*	*	*	*		*					
Field of View	*				*									*			*									
Exposure Time	*						*				*	*	*	*	*						*	*				*
Task Loading	*					*	*		*					*												*
Target Size	*	*	*		*	*	*		*			*		*	*	*	*	*	*			*		*	*	*
Viewing Distance	*		*	*	*		*		*	*				*		*	*				*			*	*	
Eye Motion	*			*		*								*								*				*
Adaptation	*						*	*	*	*	*	*		*	*	*	*	*	*		*					
Chromatic Aberration	*				*		*			*	*			*	*	*					*					
Spherical Aberration	*			*	*		*			*	*	*		*	*	*										
Physiological Nystagmus	*			*	*		*			*	*			*	*											
Size, Density Distribution of Retinal Cones	*			*	*		*			*	*			*												
Defraction	*			*	*		*				*	*		*	*											
Amount of Information	*	*	*			*			*	*					*	*						*				*

(from Semple, et al 1971)

For example, with a viewing distance of 28 inches and a required visual angle of 15 minutes, a display character should be 0.12 inches high as measured on the display surface.

- Contrast--A method of measuring contrast ratio for CRT displays expresses contrast as follows:

$$C_R = \frac{B_o + B_B}{B_B}$$

where

B_o is the brightness of the written line when ambient light is excluded

B_B is the brightness of the screen from ambient light

a contrast ratio of 2.5 to 3.5 to 1 is satisfactory for display systems operating in normal room ambience. A level of 3 to 1 is acceptable for single color displays.

- Refresh rate--The CRT display must be refreshed at a high enough frequency to avoid flicker. Thus, the refresh rate should be above the threshold for flicker perception (the lowest refresh rate at which no flicker is observed is the critical flicker fusion point--CFF). The critical frequency which satisfies the wide-angle vision at the instructor station is about 5 cps higher than that for foveal vision. Accordingly, a refresh rate greater than 47 cps is required for a flicker-free display, for a short persistence phosphor (Singer-General Precision, 1969). Flicker may also be eliminated by reducing display brightness or using longer persistence phosphors.

- Jump phenomenon--When a short persistence phosphor is used, small quick eye movements may result in the observer momentarily seeing two images on the screen. This position jump is due to the stroboscopic effect of the pulsing phosphor on eye movements (about 20 millisecond duration) made gazing at a display. Jump is observed on bright phosphor tubes with a character repetition frequency of 30 to 60 cps, a character on-time of the order of 10-50 microseconds and a character decay of 50% brightness in less than 100 microseconds (Singer-General Precision 1969). The phenomenon can be eliminated by an increase in scope persistence (e.g., about 10 milliseconds for 50% decay) or by a decrease in the brightness contrast.

- Form and spacing of characters--Character spacing, line spacing and character aspect ratio determine the packing density of characters on the display. Singer-General Precision (1969) suggests that the average width of characters should be between 65% and 80% of character height. Maximum spacing between characters should be 1/4 to 1/2 character-width laterally and 1/2 to 1 character-height vertically. The spacing between groups of letters and numbers should equal the average character width. Words written in lower-case characters tend to be less legible than those written in upper case; also, observer response time is faster in identifying upper case words.

3.4.3.2.2 Flexibility and Speed in Adjusting Display Content. Consideration must be given to insuring that the information in the visual display can be arranged and presented in any manner suitable to instructional purposes. Since all information cannot be displayed simultaneously, the instructor must be provided the flexibility to locate and call up the classes of information required for managing the shaping of behaviors without detrimental time lags in the changing of modes, pages or classes of performance or error information per student. Computer-generated, refresh CRT displays are most desirable for enhancing this capability (i.e., not only in speed and flexibility requirements but also in providing good visual quality, accuracy, resolution and registration).

3.4.3.3 Specific Display Requirements. The generic instructor station is comprised of various classes of displays and associated controls. Simply, these include: trainee station displays; displays providing device status and control (operation); auxiliary information displays, communications displays, monitoring and recording displays (e.g., CCTV, scoring readouts, hard copy) and mission displays. Our concern in this paragraph is for the information requirements pertinent to the design of mission displays. This type of display usually is specific, sometimes unique, to a class of training device. The displays are graphic/pictorial representations of specific portions of a training mission. Historically, mission displays have received greatest usage in flight simulation (e.g., graphic position plotters employing pen recording, the more recent versions interfacing with the computer and receiving X, Y position data in the form of dc analog voltages and pen-up and pen-down commands as discrete signals from the computer I/O). Current design utilizes the CRT to provide mission displays for showing vehicle ground track and position for various areas and scales.

Two examples of mission displays are provided next to illustrate the information requirements pertinent to design. The first is the graphic plotting display system employed in the helicopter synthetic flight training system, device 2B24 (NTDC 1968). A graphic CRT (one for each trainee station) provides an area for plotting the ground track of the associated helicopter against any of several preprogramed background maps and two other areas which depict time-based plots of altitude and airspeed, and selected status information. The information requirements include the following.

a. Ground track plotting--This involves the selection of appropriate scales and background maps for the cross-country mode (100 x 100 nautical mile area) and for the approach mode (10 x 10 nautical mile area). Cross-country mode characteristics include the following:

- numbered airways with intersections
- VOR stations and symbology
- LF NDB stations and symbology
- Marker beacons and symbology
- ILS facilities
- ground track vector of aircraft and ideal track
- out-of-tolerance conditions shown by symbols at the point of occurrence on the ground track. The out-of-tolerance condition is marked for the following parameters--pitch, roll, vertical velocity, rate of turn, gas producer tachometer, rotor RPM, exhaust gas temperature, torque pressure, minimum fuel, icing airspeed exceeding VNE, altitude, airspeed, and ground track.

Approach mode characteristics include:

- runways (scaled length vectors)
- obstructions and symbology
- published clearance information

b. Airspeed and altitude plotting--continuous time-based plots of airspeed and altitude are provided. Each plot is of 20 minutes duration, representing a point approximately every 4 seconds which is the instantaneous value of the parameter. Out-of-tolerance symbols are plotted along the time base to facilitate the correlation of the time plots with the ground track plot.

c. Status information--The following information is provided:

- Aircraft call number
- Training mode (automatic, checkride or semi-automatic)
- Student's name
- Training problem in progress and difficulty level
- Adaptive training score
- Student history--read from punched card
    COMP - list of completed lessons
    TIME - average time to complete
    BA - below average time to complete
    AA - above average time to complete
    SCORE - composite error rate from completed lessons
- Freeze mode indication
- Partial Panel indication that one or more cockpit instruments have programed malfunctions active
- Simulated copilot indication - when the simulated copilot is active
- Assist-student indication - flashes when the student presses his INST CALL button. The indication is removed when the instructor acknowledges the request by pushing his ACKN STUD Switch
- Student communications in progress indication - flashes when the student actuates a transmitter. The indication is removed when the instructor keys his microphone to speak over the ground transmitter of the station which the student is attempting to reach
- Malfunction indication - any one of the five malfunctions programed for a cockpit will flash when satisfaction of the programed condition is imminent
- Automatic briefing or demonstration - indication that a briefing or demonstration is in progress
- On-ground indication - weight on skids is indicated by WOS
- Initial conditions established - RDY is displayed to indicate that the trainer is ready but the student has not assumed control
- Parameter freeze - indication that one or more parameters are frozen.

The second example is provided by the mission display specified for device 2F101, T-2C Operational Flight Trainer (NTDC 1971). The display format provides for two non-equal vertically aligned display areas on a CRT. The upper display area provides for situation displays; the lower display area presents supplementary information relative to the upper display. The mission display provides the following display modes.

a. Cross-country display--the area displayed is 120 x 120 nautical miles. The upper portion of the display presents a graphic representation of all programed surface facilities. Each facility is identified with a three-letter code and the facility channel or frequency. A dotted line shows the aircraft ground track, and an aircraft symbol indicates present aircraft position. The bottom part of the display contains continuous tabular readouts for aircraft latitude, longitude, altitude, heading, ground-speed, DME reading of the BDHI, wind, and time from the start of the mission. The wind indication is graphically represented and the simulated aircraft ground track plot is the vector sum of the true heading horizontal airspeed vector and the wind velocity vector. Four direction arrows are provided as an assist in slewing the display with a lightpen. Figure 21 is an example of a cross-country mission CRT display.

b. Approach area display--the approach area is 30 x 30 nautical miles. This display is automatically generated and replaces the cross-country display when the aircraft is within 30 nautical miles of the surface facility in time. The center of the display is the in-tune surface facility. The representation of the surface facilities, the simulated aircraft, and the aircraft track is the same as for the cross-country display. The bottom part of the display is also the same as for the cross-country display. Figure 22 is an example of the approach area display.

c. Ground Controlled Approach (GCA) display--an area of 10 nautical miles from touchdown is presented. The upper part of the CRT is an elevation and azimuth display. Runway heading and glide slope elevation is that of the pertinent surface facility in the approach display mode. Aircraft position is represented by an aircraft symbol with its altitude and ground track represented by dashed lines on the az-el displays. The lower display area on the CRT presents continuous tabular readings for aircraft latitude, longitude, altitude, heading, ground speed, DME reading of the BDHI, wind, and time from the start of the mission. Wind indication is graphically represented. Instructions based on the aircraft position are displayed in this area. Figure 23 is an example of the GCA display.

3.4.3.4 Controls for Display Selection and Modification. The design goal is to provide manual input means, compatible with the CRT displays, permitting communication with the computer with a minimum of intermediate

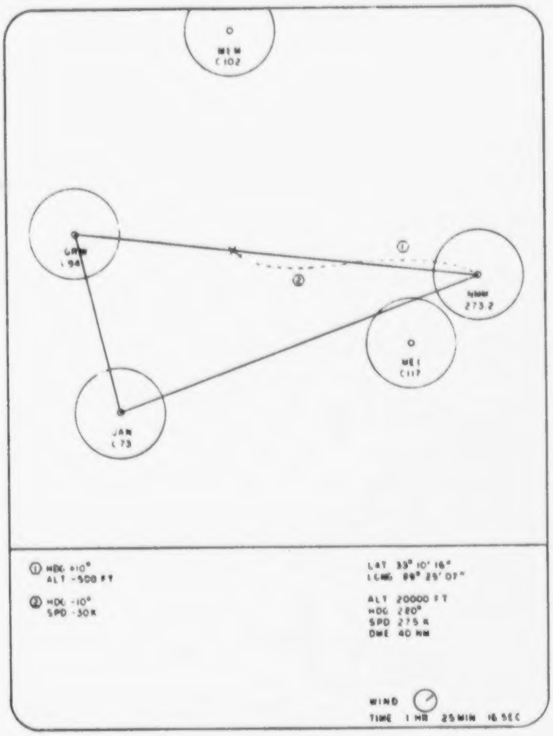
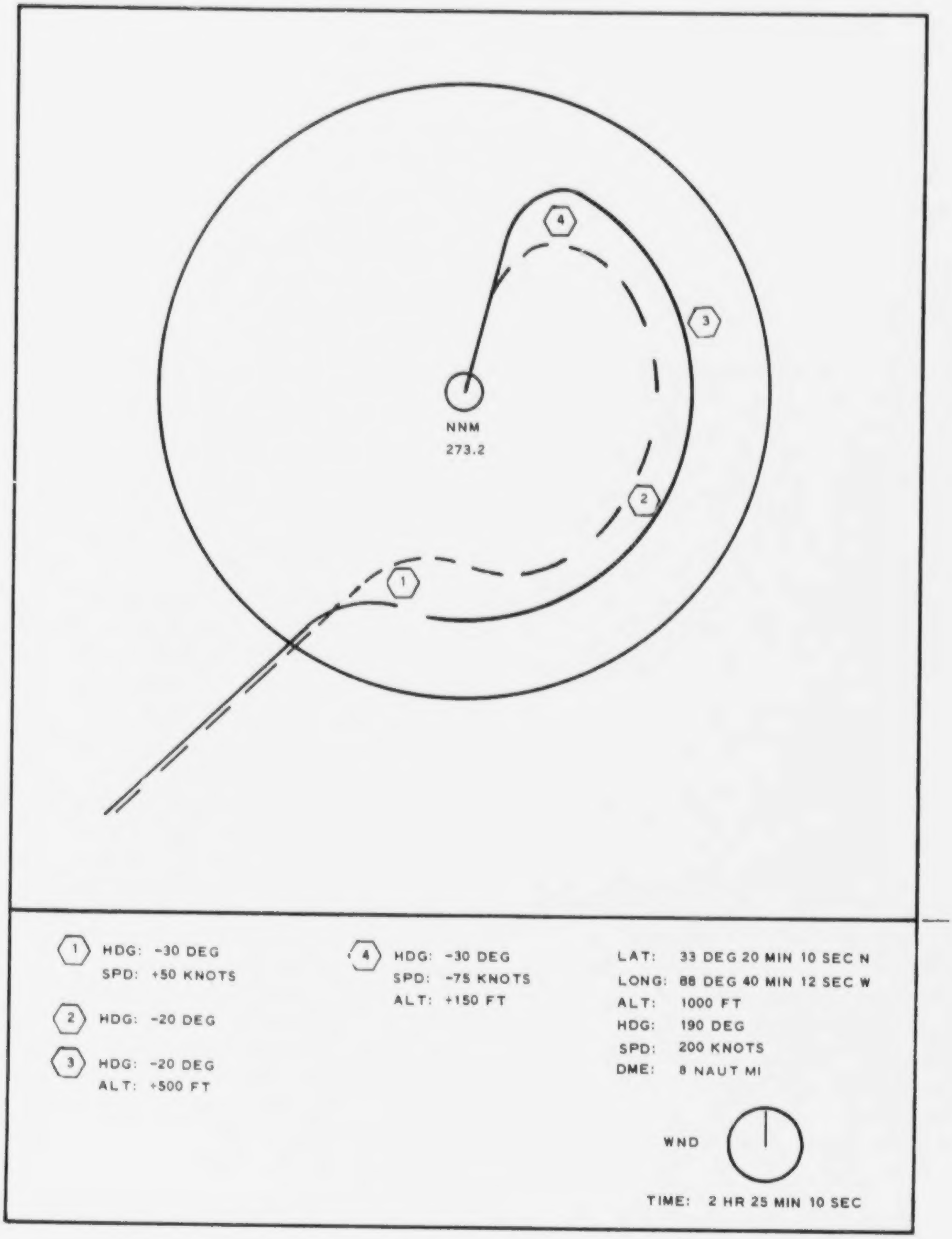


Figure 21. Cross-Country Mission CRT Display.

transformation of information. The controls must be: compatible with tabular and graphic formats, flexible, simple to operate, and conservative of console space.

The console keyboards (alphanumeric and functions) and the lightpen are currently the most effective means for calling up, changing and modifying displays of student performance data and mission information and for providing the required control for instructional actions (see Chapter 3.4.9). The instructor is provided the flexibility for selecting specific classes of data and initiating desired instruction pertinent to each student, as required. The controls for the instructor station display system must be capable of interacting with the CRT displays in all pertinent operating modes for all trainee stations. The specific information requirements for design are determined within the following control functions:



(1) HDG: -30 DEG
SPD: +50 KNOTS

(2) HDG: -20 DEG

(3) HDG: -20 DEG
ALT: +500 FT

(4) HDG: -30 DEG
SPD: -75 KNOTS
ALT: +150 FT

LAT: 33 DEG 20 MIN 10 SEC N
LONG: 88 DEG 40 MIN 12 SEC W
ALT: 1000 FT
HDG: 190 DEG
SPD: 200 KNOTS
DME: 8 NAUT MI

TIME: 2 HR 25 MIN 10 SEC

Figure 22. Approach Area Display.

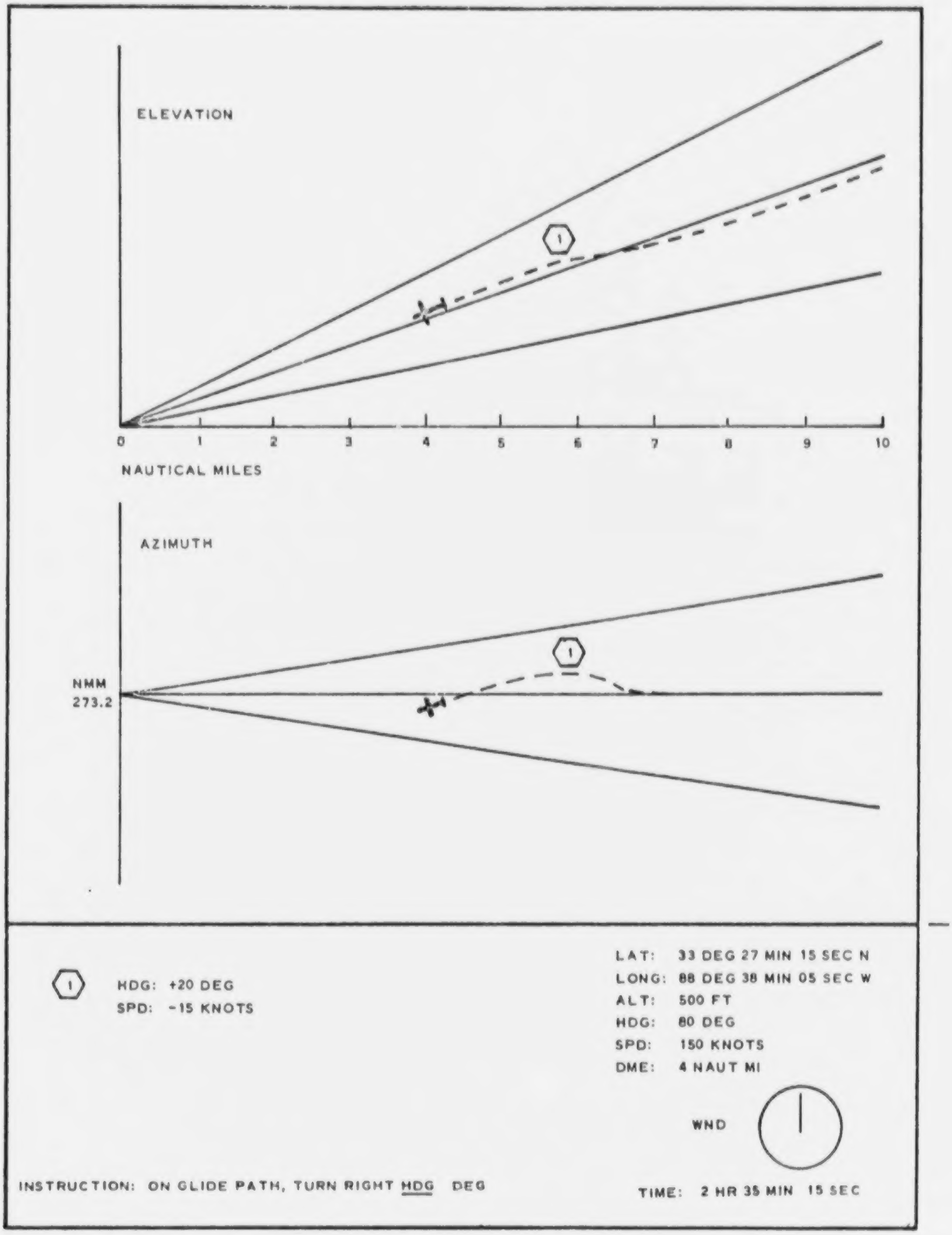


Figure 23. GCA Display.

- select instructor display system modes involved in off-line and on-line operations (e.g., DRED, PLAN, PROBLEM and CRITIQUE modes)
- select displays associated with monitoring, evaluating and scoring student performances in the PROBLEM MODE (e.g., error, performance and status information)
- select specific mission areas or events (e.g., mission displays, procedural performance (TMS))
- modify preprogramed scenarios enroute during the exercise
- select and control the display of specific CRT pagination (alphanumeric and graphic)
- initiate desired instructional actions during the exercise (e.g., reinstruction, demonstration)
- select hard copy records of student performance.

3.4.4 INFORMATION DISPLAY REQUIREMENTS FOR MONITORING, EVALUATING AND SCORING PERFORMANCE

The specification of display requirements is largely dependent on the information requirements in terms of: content, amount, variety and speed of information change, complexity and the student-to-instructor ratios (i.e., in multiple but independent trainee stations). The business of shaping student behaviors during a series of exercises requires careful thought about the manner in which student performance and system information is displayed and on the concomitant control capability. In short, an organized, unambiguous, fast access information format commensurate with the device under consideration is required.

The emphasis is placed on achieving sufficient information to monitor and evaluate the significant aspects of any student's performance and system status at any time during the exercise. Thus, efficiency and flexibility in information presentation and updating, and in information selection is the desired design goal. Implied in this are the human engineering requirements in layout and usage patterns to minimize confusion, distraction and clutter in the displayed information.

The information requirements outlined below provide a comprehensive listing to account for most device classes and training situations. The human factors specialist need only consider that which is pertinent to the contemplated device. (This is in keeping with our intent to provide guidance and support to the human factors effort in developing the technical approaches to any device design.) The listing accounts for the most demanding instructional situations and assumes the following: multi-format CRTs; multiple displays and multiple students undergoing simultaneous but independent instruction. The following information classes should be considered.

- Mission data--The information includes: a listing of the training problems, the training problem number selected, active trainee stations (multiple, independent trainee stations) and the students assigned to a specific instructor/device operator.

- Display of student history--This is information on the training history of each student and is displayed at the instructor station when the student is in the simulator (e.g., provided by a card reader to read into the computer for data entry purpose).

- Mission/scenario area--This involves the display of mission, tactical environment, navigational areas (latitude, longitude) or relative geometry in the pertinent display modes.

- Own vehicle and support/friendly vehicle display--This includes identity, position, track (past history).

- Other mission events/installations--This includes fixed installations (bases, radio navigational facilities) or mission actions (e.g., radiating EW emitters, airborne interceptors, etc.).

- Target data

    - range, bearing, heading, altitude/depth information
    - target contact/detection (onset, attenuation, disappearance as a function of range and environmental conditions)
    - tracks/position (differentiation of targets)

- Total situation display (e.g., tactical engagement, GCA, plot of total ground track with tolerance bands and checkpoints on which student track history is overlaid, etc.).

- Environment--(all pertinent parameters).

- Console operating modes--This refers to the display of the different modes of operation required to control the total training exercise and to monitor and evaluate student performance (see Chapter 3.4.6).

- Indication of system state or mode of operation and present phase or point in the mission or exercise.

- Location (geographic) of all students in the exercise.

- Variance of vehicles about the ideal track (e.g., aircraft deviations from true ground track).

- Status of events initiated in the trainee station (e.g., indication of jammer activation, deployment of sonobuoys, chaff dispense, weapon selection and deployment, "fanfare" deployment, etc.).

- Indication of each student/team control or tactical action and consequences of this action (e.g., range scale settings, sector selection, operating mode selection, radio frequencies selection, etc.).

- Indication (and time) of student/team detection and identification of targets, from onset.

- Indication of instructor actions, initiated and under current control or monitoring.

- Instructor control of vehicles--This refers to the information needed for controlling a submarine target or "flying" an aircraft (e.g., position, heading, altitude/depth, speed, track of the pertinent vehicle).

- Performance information on each student or team--This refers to error/status/activity information (i.e., immediate or time sampling by type, parameter or error class).

- Error alert indication of out-of-tolerance performance (e.g., computer freeze; audio message to student).

- Indication of any/all vehicles out-of-tolerance (e.g., bearing error, offset error, latitude and longitude error).

- Indication of adequacy of student procedural performance--This refers to checklist procedures (normal and emergency) in sequence and in error (omission and commission).

- Indication of student/team error deviation from programed tolerances--This refers to information on performance which exceeds the error envelops set for the exercise (total error, errors per parameter, errors per class).

- Types and number of communications errors.

- Communications-navigation indications (e.g., prerecorded automatic ATC clearance given the student).

- Indication of the actions requested of a student--This refers to specific questions (messages) presented from a finite list (e.g., specific stimuli (request for an activity) provided by an annunciator panel, and showing student response to the message and the resultant feedback of performance information).

- Indication of malfunctions/emergencies/failures (e.g., specific types and locations, aircraft partial panel mode).

- Indication of all critical time and event happenings enroute during the exercise (selectable on demand).

- Visual display of student instrument panel status and control manipulations (e.g., via CCTV).

- Status information requests--This refers to the type and frequency of student requests for assistance relative to geographic position (where am I?), target deportment, etc.

3.4.5 CONTROL CAPABILITIES FOR MONITORING, EVALUATING AND SCORING PERFORMANCE

A number of classes of controls, many of which are direct counterparts to the display capability, serve to operate the training device and to enable the shaping of student behaviors. A capability is required at the instructor console to control the information displayed to the student as well as to control the information displayed about student and about system performance.

Instructor console controls may be defined according to the functions performed, which in turn influences decisions on control selection and on control placement in the console layout. Four groupings of controls can be identified.

- Mission/instructional control (on-line)--This is the major grouping of controls. They enable the structuring and control of training during the exercise, and range from switches through control-display indicators to manual input devices. In multi-man trainers where fast access to much information in multi-formats is necessary, the selection of manual input controls compatible with the displays is a crucial determination for training management. (See Chapter 3.4.9.)

- Scenario modification (off-line)--These are the controls for modifying or generating new scenarios where preprogramed training exercises are employed. Where automated preprogramed exercises are not warranted, the pertinent controls are those employed in the manual setup of the initial conditions for an exercise.

- Ancillary and power supply--These are the controls associated with the operation of the training device, e.g., power to the instructor console, exercise initiation, emergency stop, lamp test, etc.

- Communications--These are standard controls, most often, replicas of existing operational equipment for two-way communications with: the student(s) (individually or grouped); the remote instructor(s); the training device operator; and other associated personnel.

The following control capabilities should be accounted for, as appropriate, to the training device under consideration.

- Device operation--This involves controls for power, checks, system initialization, problem start, halt and override.

- Trainee Station Controls
    - power
    - motion system activation and deactivation
    - playback of control performance
    - placement of aircraft under simulated co-pilot control
    - display of GCA command information (e.g., on graphic plotter displays)
    - instruct hard copy printer

- Means for displaying student history (multiple, independent student context).

- Means for positioning units in an exercise, both initially at problem start and during the exercise.

- Environment (media) controls--e.g., earth's atmosphere, water conditions.

- Means for selecting mission/scenario area or scale.

- Means for inserting and manipulating targets in an exercise (e.g., time and position of entering targets, repositioning of targets, control of the range between targets or between own vehicle and target(s)).

- Means for inserting parameters and events at prescribed times in an exercise (manual insertion in scenarios not preprogramed).

- Means for inserting non-programed events or eliminating programed events in preprogramed scenarios--This capability provides the instructor various options in developing instructional strategies tailored to the individual student's abilities. The instructor has the option to manually override the entry of a prescribed normal or emergency event when it is in position for entering the mission (for students who are below performance expectations). Additional normal and emergency events may be inserted into the preprogramed scenario to advance students at their best rate of progression (for students who exceed scenario requirements).

- Means for selecting CRT display modes and formats--This is a complex and crucial requirement and affects significantly the total instructional control capability. Based on computer assistance in monitoring, evaluating and scoring performance, means are required for selecting and controlling pertinent training parameters from the complete training data on all students. The control design issues are the following:

- format selection: alphanumeric and pictorial representation

- display mode selection: a variety of operational modes are pertinent depending on the specific device requirements. Basically, however, the control capability subsumes the basic display modes of:

  problem setup
  monitoring
  error evaluation
  error alert (out-of-tolerance)
  scenario/problem modification
  demonstration

- selection of specific data: various aspects of performance information must be available. This includes the capability to select information on:

  individual/all students
  system performance
  performance error data
  specific aspects of performance as a function of monitoring, evaluating, or scoring modes

- Means for varying task difficulty by freezing (holding constant) individual parameters in an exercise for a given student (e.g., during initial instruction in a flight trainer, altitude may be held constant to enable the student to concentrate on heading control; axis lock, enabling the lock or release of one or more motion axes (roll, pitch, yaw)).

- Means for inserting/denying failures or emergencies into an exercise.

- Means for direct access to the device computation system (e.g., manual input controls such as keyboards, lightpen, etc.).

- Communications controls.

- Means for controlling vehicles--e.g., controls for steering a submarine, "flying" an aircraft.

- Controls to tally defined complex responses of students (e.g., student responses to communications procedures, problem solutions).

- Means for recycling the system in automated preprogramed training exercises.

  - reinstruction: recycling a portion of the mission to direct an errant student to accomplish again that which he has just completed.

  - remedial branching: when student performance deviation or error rate exceeds the preset criterion for an error class/type, the student is automatically recycled to a remedial training segment.

  - capability to recycle students who exceed performance expectations to another segment more appropriate to their demonstrated skills.

- Means for initiating and terminating demonstrations, in real-time and in slow-time.

- Means for selecting performance information to be scored and recorded.

- Means for inserting changes in the preset error tolerances--this refers to the capability to change error tolerances (preprogramed increments) when student error per class exceeds the preset tolerances.

- Means for monitoring and controlling student procedural performance--This refers to the control in instruction in defined procedural sequences, e.g., checklist procedures (normal and emergency) in flight simulators.

- Means for selecting hard copy records of student performance, both enroute during the mission and after exercise completion, for critique purposes.

- Interlock controls between the instructor station and the training device operator console--This concerns minimizing the possibility of an inadvertent or undesirable insertion of additional parameters to a preprogramed scenario. For example, a key switch may be employed which must be activated at the TDO console prior to enabling any parameter insertions via controls at the instructor console.

3.4.6 INSTRUCTIONAL OPTIONS CAPABILITY

A goal in instructor station design is to provide an inherent flexibility in operations sufficient to the development of instructional strategies pertinent to each student, consonant with the purpose of the training device. The basic requirement is the specification of software programing and hardware capabilities which provide the relevant display and control modes and the instructional assists and guidance supports in the management of training. In short, the instructional efficacy of the training system hinges on the availability of these kinds of features in design.

This flexibility in instruction which takes advantage of the most recent training technology is accomplished in various ways. To facilitate discussion, the varieties of instructional options are organized as follows:

- modes of operation for monitoring and evaluating student performance
- guidance supports
- specific stimulus presentation
- assists for controlling problem complexity
- knowledge of results
- mediation

In most instances, programs are required for use with the simulation program to enable instructor manipulation of instructional events and exercise parameters. The information requirements for achieving the capabilities defined in each of the above listed categories are described next.

3.4.6.1 Modes of Operation for Monitoring and Evaluating Student Performance. Three basic trainer modes are utilized, defined in terms of instructor control and involvement.

- automatic mode--This is predicated on an automated monitor, evaluation and scoring system and preprogramed training exercises. The automated training features include, demonstrations, problem sequencing, student performance and error recording, out-of-tolerance alerts and adaptive sequencing. Student performance is continually evaluated by the computer subsystem (comparison of actual with preset tolerances) and hard copy records of performance are available.

The instructor is not involved unless the student is unable to perform within expectations or requests assistance. This mode includes the evaluation (checkride) exercise employing a standard preprogramed exercise with automatic performance recording and error scoring for later off-line analysis with no instructor intervention unless the student is unable to continue.

- semi-automatic mode--This is predicated on the automated instructional assists indicated above (i.e., preprogramed scenarios, automated scoring and various automatic error alerting features), but is instructor-controlled to achieve the full expression of the manual adaptive capability.
- manual mode--This is predicated on instructor involvement in structuring and controlling training and includes the manual installation (via controls and displays) of the initial conditions and the control of mission events via a script or other bases. Performance evaluation may be based on judgments about performance via displayed information and student actions and communications, with or without time and event recording of measurement information.

Our emphasis is placed primarily on semi-automated trainer operations since the instructional options place the greatest demands on the display and control capabilities in interaction with the computer programing. The information requirements for this mode center on the displayed information and relevant controls for selecting, monitoring and evaluating all aspects of student performance and the means for controlling the entire trainer and the training exercise. The basic variations in the CRT display(s) depend on the instructional functions and the information desired. These include:

a. monitoring mode--For determining the performance and mission status of each student irrespective of specific errors made or out-of-tolerance conditions.

b. monitoring and error evaluation mode--Continual interrogation is made of specific performance information as the necessary input for decisions on training strategy (i.e., manual adaptive capability--the options include: continue as programed; freeze and reinstruct; freeze and demonstrate; increase/decrease problem difficulty by inserting/omitting events in the preprogramed scenario).

c. error alert mode--Special case of error evaluation where automatic freeze occurs when a student exceeds a preset error envelop (e.g., total or per parameter). Modified error tolerances (Δ error) must be established and inserted via appropriate controls into the computer.

d. demonstration mode--Display of information demonstrating to the student desired or ideal performance or aspects of this performance in real or slow-time (e.g., maneuvers, instrument and control activations, specific EW emitter signatures, etc.).

e. specific mission modes--Trainer mode and submodes particular to the operational counterpart.

3.4.6.1.1 Display Requirements--The following determinations must be made to achieve the display content and flexibility in data presentation:

- Display format for each mode.
- Types of display.
- Events to portray per display.
- CRT page formats.
- Identification of the data common to each display mode.
- Size of the mission area.
- Information specific to the contemplated device.
- Situational (graphic) display of total/summary.

(These requirements are described in detail in Chapter 3.4.3)

3.4.6.1.2 Control Requirements--The following requirements must be achieved:

- Controls for changing or modifying mission areas, CRT pages, operational modes.

- Controls for calling up specific information classes, erasing information.

- Controls for recycling portions of the displayed information.

3.4.6.1.3 Instructor console modes of operation for an Air Navigation Trainer--An example of the information requirements for the operational modes proposed for Device 1D23 (Bark, et al 1969) is shown below. Basic formats for visual presentation were defined to monitor and control the enroute exercise, control moving navigational facilities, monitor and assist students and evaluate student performance. This problem mode was divided into four submodes:

- all aircraft--This mode provides flight track and performance information on all forty students (except when operating as two distinct trainers, i.e., twenty trainee stations per instructor console).
- group aircraft--This mode is identical to the all aircraft mode except that only ten trainee stations are represented by the CRT presentation. Information pertinent to any trainee station which exceeds the established error tolerances, will blink on the CRT.
- Aircraft out-of-tolerance--This mode presents only information on trainee stations that have exceeded the established limitations.
- Specific aircraft--This mode is identical to the aircraft out-of-tolerance mode except that information on a single trainee station is selectable at any given time.

All tabular information presented during the problem mode common to the total training problem is common to the submodes and appears in the same formats and in the same locations. An example of the CRT display for the specific aircraft submode is shown in Figure 24.

A keyboard control capability is provided for mode selection. A key is provided for each display mode and for selecting the scale of the geographic plot area.

> NOTE: In addition to the problem mode, additional modes are employed in off-line operations. These are: the daily readiness mode (DRD) for monitoring and controlling the checkout of the trainer; the problem setup mode (PSU) for selecting or generating a preprogramed lesson from the trainer mass memory storage; the replay mode (RPL) which provides the means for replay of the exercise in real or fast time; and the inspect and change mode (IAC) which permits the instructor to inspect and change the library of instructor-controlled parameters.

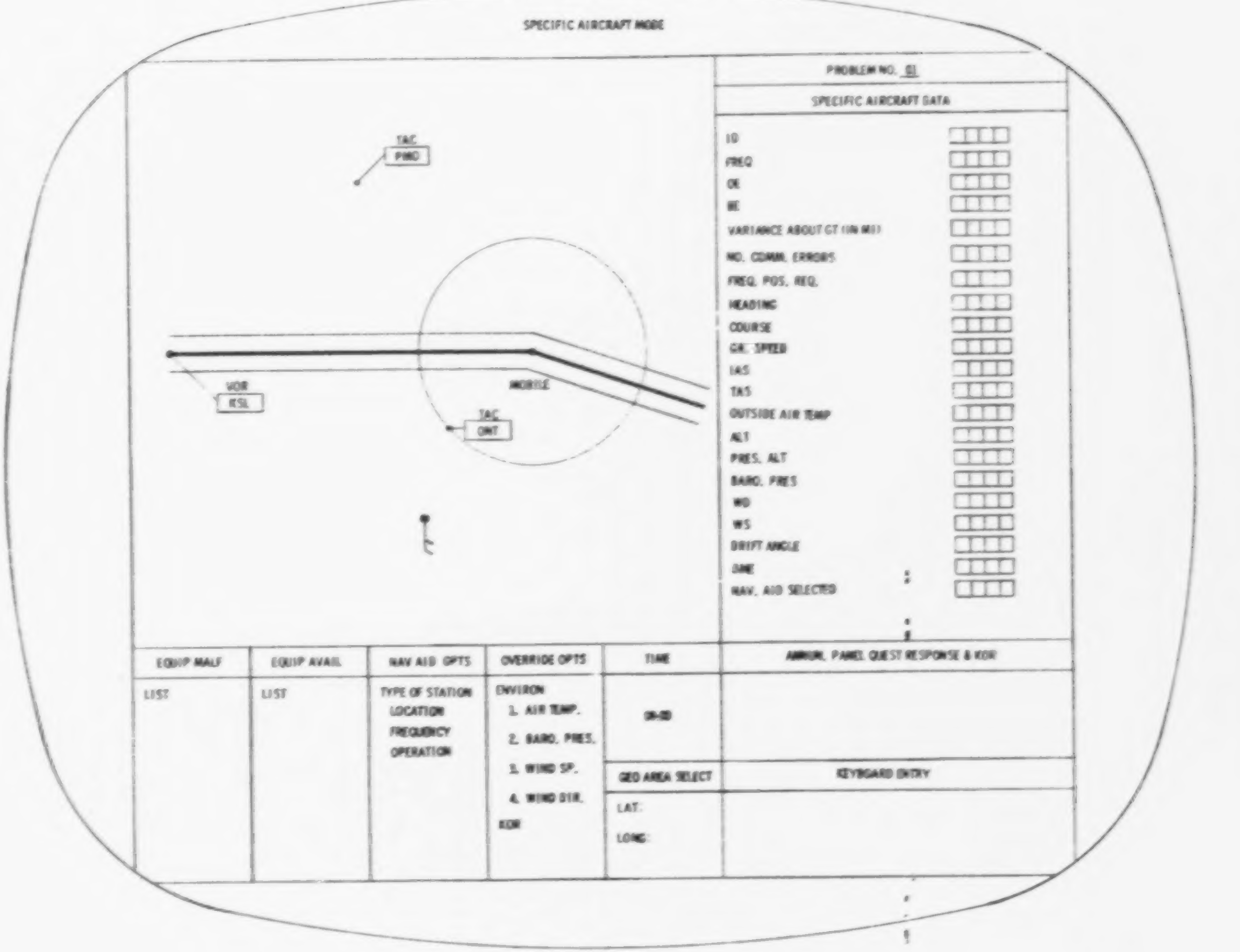


Figure 24. Specific Aircraft Mode.
(from Bark, et al 1969)

3.4.6.2 Guidance Supports. A means for providing supplementary information about performance involves the use of cues and prompts in design. The value of these techniques which provide guidance during training, is well recognized; it is the matter of implementation of these design options that is of interest here. Our concern includes both the design of supports provided to the student and the assistance provided the instructor to simplify and improve his instruction.

So far as the student's progress is at issue, considerable data on learning have indicated that task relevant guidance (i.e., stimulus support) is particularly useful during initial learning, for it emphasizes the relevant aspects of performance, limits exploration time and minimizes gross errors in performance. As learning progresses, these supports are eventually withdrawn until the student responds to the stimuli found in terminal performance. The information requirements for providing various means of guidance support are described next.

3.4.6.2.1 Demonstration--This refers to the capability to provide the student preprogramed examples of training problem solutions that must be mastered. Examples are provided to demonstrate desired performance of selected system behavior patterns which may be used at any point in the exercise (during briefing or enroute in the problem) as dictated by the mission requirements and by the adequacy of student performance. The pertinent content covers a broad range, including: instrument and control activations of idealized maneuvers of an aircraft; preprogramed signatures of classes of EW emitter signals and characteristics of preprogramed emitters; emergency or malfunction conditions; a ground-controlled approach (GCA) with voice commentary; and specific control requirements in a task or job segment.

The information requirements for providing this design capability include the following:

- definition of the specific demonstration events required and the total number that will be programed.
- definition of the specific content and length of each demonstration event--This includes the initial conditions and prescribed dynamic data (speed, rates, rate changes) to execute the defined problem solution or maneuver with synchronized verbal commentary (as appropriate), or the series of points or the patterns in sequence that define the desired display to the student.
- specification of the tolerances in each problem solution to provide the desired fidelity in time and movement,

i.e., technical accuracy commensurate with the training objectives (idealized/school solution; desired sequence, etc.).

- specification of where in the mission scenario preprogramed demonstrations are desired.
- specification of performance conditions (e.g., error tolerances exceeded by the student) which initiate automatically the demonstration required to assist the student to perform within tolerances.
- specification of the performance data display(s) and controls to enable the instructor to select and initiate a defined preprogramed demonstration (as required in tailoring the instructional strategy for a given student).
- controls for slow- or real-time demonstration; for halting the demonstration in progress; and to access a portion of the demonstration sequence.
- capability for generating new or modified demonstration sequences (off-line).

An example of the capability for automated demonstrations of training problem solutions is provided by Device 2B24, Synthetic Flight Trainer System. A library of demonstrations (10 problem solutions) is provided. Each demonstration contains the initial condition data and other data necessary to execute the demonstration flight. These data are retained in auxiliary storage but are accessible during a training session without instructor intervention. Upon request by the student or by the instructor, each demonstration is executed in such a manner that the cockpit instruments and the motion module exhibit the movements which would be experienced if the demonstration were actually being flown. A synchronized pre-recorded verbal explanation and commentary is provided for each example. The demonstration is provided in real-time or in slow-time (one unit of real-time equals two units of slow-time) or in some combination of real-time and slow-time as appropriate for student understanding of the problem being demonstrated. Emphasis is placed upon instructional quality as well as on technical accuracy of the demonstration. The following demonstrations are programed.

- The interpretation of attitude and flight control instruments and relationships between displayed information and control movements.

- VOR approach, including reporting procedures and execution of a missed approach.
- A tactical ADF approach, including reporting procedures and execution of a missed approach.
- A standard ADF approach, including reporting procedures, wind drift correction, and execution of a missed approach.
- An ILS approach, including wind-drift correction, reporting procedures, and execution of a missed approach.
- Control of the aircraft during climbs, descents, turns, climbing and descending turns and level flight by reference to attitude instruments.
- Interpretation of navigation instruments.
- Holding at an intersection, including entry from 90° off-axis, wind-drift correction and departure at a predetermined time.
- An in-flight engine failure and air restart.
- An instrument takeoff.

An example of a demonstration segment is shown in Table 10. It depicts an instrument takeoff (ITO) for a helicopter[1] and involves the briefing, the complete ITO, and the ITO in slow-time.

3.4.6.2.2 Reinstruction. Consistent with the manual adaptive capability is the reinstruction mode. This enables the instructor to return to an earlier portion of a mission for any or all students who perform below expectations on the given exercise. The reinstruction requires that the student perform again that which he has just completed (e.g., a segment, a flight leg or portion of a leg). To accomplish this, the instructor requires the following (assuming the automated scoring capability):

- dynamic display (CRT) of student performance information in all PROBLEM modes (alphanumeric and graphic formats)

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[1] This work involving the HH-52A helicopter was accomplished by the Human Resources Research Organization for the Coast Guard (see for example, Hall, Caro, Jolley and Brown 1969).

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER)

Segment 0: Briefing

Time In Segment	System Tasks		Activation Criteria	Pilot Tasks	Audio
	Initial Conditions			Initial Conditions	
	Altitude	218 ft.		Wheels - Down	
	Airspeed	5 kt+		Collective	
	Heading	360°		Friction - Off	
	Turn Rate	0			
	Rate of Climb	0			
	Rotor RPM	103%			
	Position				
	Station	MO Outer Marker			
	Range	4.6 n. mi.*			
	Bearing	140°*			
	Problem Time	23:30:00			
	Elapsed Time	Reset			
	Temperature	87°			
	Baro. Pressure	29.78			
	Wind	360°/5 kt			
	Rain	Off			
	Center of Grav.	255 in.			
	Gross weight	7700 lbs.			
	Fuel Remaining				
	Fwd	1000 lbs.			
	Aft	140 lbs.			

*Adjust as necessary to put aircraft on Runway 36 at Bates.
+Or as results with aircraft in a 5 kt. headwind.

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER) (Continued)

Segment 0: Briefing (Continued)

Time In Segment	System Tasks	Activation Criteria	Pilot Tasks	Audio
	Initial Conditions		Initial Conditions	
	Establish above initial conditions. Position audio tape to start of ITO demonstration briefing. Set segment indicator to 0.	Activation of "Demo" switch with select switch set to 4.0		
	Freeze the problem.	When above system tasks are accomplished.		
	Start audio.	When freeze is removed after completion of above system tasks.		This is a demonstration of an instrument takeoff from the ground at Bates Field. All necessary helicopter systems are activated and functioning normally, and the takeoff checklist has been completed. The weather at Bates is 200ft. overcast and 1/4

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER) (Continued)

Segment 0: Briefing (Continued)

Time In Segment	System Tasks	Activation Criteria	Pilot Tasks	Audio
	Initial Conditions		Initial Conditions	
				mile visibility in fog; wind 360° at 5 kt; and altimeter 29.78. The takeoff will occur from Runway 36. The instrument panel now indicates the parameter values which will be in effect when the demonstration starts. Notice the helicopter is headed into the wind. The pilots' feet should be on the deck. The ITO will begin by increasing collective to obtain 95% torque.

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER)(Continued)

Time In Segment	System Tasks	Activation Criteria	Pilot Tasks	Audio
Segment 0: Briefing (Continued)				
	Initial Conditions		Initial Conditions	
				The demonstration will now be frozen. If you have any questions, ask the instructor. Inform him when you are ready for the demonstration to continue.
	Freeze problem.	At end of above audio.		
Segment 1. Complete ITC				
	Same as segment 0.			
0:00	Set segment indicator to 1. Start problem as specified in initial conditions. Start audio	Removal of problem freeze.		As power is applied, the wings must be maintained level and the nose on the horizon. (6 sec)
0:03	Start collective increase to 95% torque. Rate of increase:**			

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER)(Continued)

Segment 1: Complete ITO (Continued)				
Time In Segment	System Tasks	Activation Criteria	Pilot Tasks	Audio
	Initial Conditions		Initial Conditions	
** (0:07)	Lift-off			
* (0:10)	Start audio.	At 40 ft. altitude.		As the aircraft passes through 40 to 60 ft., the nose is positioned 5° below the horizon. (8 sec)
** (0:17)	Start to push the nose to 5° down rate of change**	At 50 ft. altitude.		
* (0:28)	Start audio.			Approaching, 55 kt. airspeed, the nose is positioned to 3° above the horizon. (6 sec)
** (0:32)	Start to pull the nose to 3° up Rate of change.**	At 55 kt. airspeed.		
* (0:36)	Start audio.			The aircraft is trimmed for a climb at 55 kts. (4 sec)

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER)(Continued)

Time In Segment	System Tasks	Activation Criteria	Pilot Tasks	Audio
Segment 1: Complete ITO (Continued)				
	Initial Conditions		Initial Conditions	
* (0:50)	Start audio.			At 1000 ft. altitude, a transition to a 70 kt. climb would be accomplished (6 sec)
* (1:03)	Start audio.			The demonstration is ended and the trainer will freeze. If you have any questions discuss them with your instructor. (7 sec)
* (1:10)	End segment. Freeze problem.	Upon completion of the audio above.		
Segment 2: Complete ITO (Slow-Time)				
	Same as segment 0.		Same as segment 0.	
	Establish above initial conditions. Position the audio tape to the start of the ITO demonstration briefing in slow-time	Activation of "Demo" switch with select switch set to 4.2.		

*Time must be determined to synchronize audio with system event described in audio.

**Correct value must be computed from model. Times in parens are estimates.

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER)(Continued)

Segment 2: Complete ITO (Slow-Time) (Continued)

Time In Segment	System Tasks	Activation Criteria	Pilot Tasks	Audio
	Initial Conditions		Initial Conditions	
	Freeze the problem.	When above system tasks are accomplished.		
0:00	Set segment indicator to 2. Start problem as specified in initial conditions. Start audio.	Removal of problem freeze.		This is demonstration of an ITO in slow motion. The ITO is started by a smooth application of power pull to 95% torque. Any hesitation in collective pull above 50% torque should be avoided to prevent lateral "slip" during lift-off. Check to insure the ASE maintains heading. It is important to maintain wings level and nose on the horizon during
0:00	Start collective pull to 95% torque rate of increase.** Start audio.			
** (0:14)	Lift-off			

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER)(Continued)

Segment 2: Complete ITO (Slow-Time)(Continued)

Time In Segment	System Tasks	Activation Criteria	Pilot Tasks	Audio
	Initial Conditions		Initial Conditions	
				the first part of the ITO. Note the cyclic movements required to hold this attitude. (27 sec)
* (0:30)	Start audio.			When an altitude of 40 to 60 ft. is obtained with a positive rate of climb, the nose is positioned to 5° below the horizon. A positive rate of climb is indicated by upward movement on the radar altimeter pointer. The nose is positioned with

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER)(Continued)

Segment 2: Complete ITO (Slow-Time)(Continued)				
Time In Segment	System Tasks	Activation Criteria	Pilot Tasks	Audio
	Initial Conditions		Initial Conditions	
				control pressure rather than with beeper trim. Note how far forward the cyclic has been positioned to obtain 5° nose down. As airspeed increases the cyclic must be pushed still further forward to maintain the 5° nose down, attitude. Note that airspeed indications are erratic. (31 sec)
** (0:34)	Start to push the nose to 5° down Rate of change**			
** (1:04)	Start to pull nose to 3° up. Start audio.	At 55 kt. airspeed.		Approaching 55 kt, cyclic pressure is released to obtain a nose attitude of 3° above the horizon. (6 sec)

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER)(Continued)

Segment 2: Complete ITO (Slow-Time)(Continued)

Time In Segment	System Tasks	Activation Criteria	Pilot Tasks	Audio
	Initial Conditions		Initial Conditions	
**	Stabilize airspeed at 55 kt.			
* (1:30)	Start audio.			When a 55 kt. climb has been established, the aircraft is trimmed to climb at that airspeed. (6 sec)
* (1:40)	Start audio.			At 1000 ft. altitude, a transition to a 70 kt. climb would be accomplished. (6 sec)
* (2:06)	Start audio.			The demonstration is ended and the trainer will freeze. If you have any questions, discuss them with your instructor. (8 sec)
2:20	End of segment. Freeze trainer.			

*Determine time to synchronize audio with system events described in audio.
**Correct value must be computed from model. Times in parens are estimates.

TABLE 10. DEMONSTRATION-INSTRUMENT TAKEOFF (HH-52A HELICOPTER) (Continued)

Segment 1: Complete ITO

APPROX TIME	SYSTEM TASKS	ACTIVATION CRITERIA	PILOT TASKS	AIR SP	ALT	HD	FLT PATH	CLIMB RATE	TURN RATE	PITCH ANGLE	BANK ANGLE	TQ	BALL DISPL.
	Initial Conditions Same as Segment 0.												
0:00	Recognize beginning of seg. and: 1. Set Segment Indicator to 1. 2. Start scoring heading and pitch. 3. Start problem Time clock.	When problem is unfrozen at specified initial conditions.	Increase collective to start ITO.			360 ±5°				0 ± 2°			
(0:03)	Start scoring bank angle, torque and ball displacement.	3 sec after 70% torque.									0±2°	95 ±5%	0±¼bw
(0:06)	Change pitch tolerance.	At 40 ft altitude.	Start to push nose to 5° down at 40 to 60 ft.							-2°±4°			
(0:13)	Change pitch tolerance.	At 60 ft altitude.								-5±2°			
(0:27)	Change pitch tolerance and start scoring airspeed.	At 50 kt.		55±5kt						0±5°			
(0:32)	Change pitch tolerance.	At 55 kt.	Start to beep nose to 3° up at 55 kt. Establish and maintain 55 kt airspeed.							+3±2°			
(1:02)	End of segment. Freeze problem.	30 sec after occurrence of above.		↓		↓				↓	↓	↓	↓

NOTE: Times in parens estimated and are referenced to 70% torque value (increasing).

(Based on HumRRO documentation for the HH52A Helicopter Simulator.)

- display of error data and out-of-tolerance data (exceeding preset tolerances) for all students
- controls to halt the exercise for the given student and recycle the mission to the desired segment.

This provides a means for controlling problem difficulty consistent with the student's demonstrated ability. In the same sense, the instructor has the option to nullify certain events in a preprogramed scenario (e.g., eliminate a malfunction already programed, eliminate a programed airborne interceptor attack in an EW mission) for students performing poorly. He may also insert new events in addition to those in the preprogramed scenario for the student whose performance exceeds the mission requirements. This provides for a controlled increase in problem difficulty for the purpose of keeping each student at the threshold of his ability during the training program.

Difficulty level may also be under computer control. In this case, performance measures are continuously compared with preset standards, and when student error rate exceeds the defined tolerances for an error type or other grouping, the problem is halted and the student is branched automatically to a remedial training segment. The branching decisions and the rules for resumption of the standard exercise must be programed into the computer.

3.4.6.3 Specific Stimulus Presentation. In complex training environments, stimuli associated with sequences of performance are often vague and not easily identified. This hampers the control of the instructional process. There are instances, however, where specific stimuli can be controlled to advantage in the shaping of student behaviors. In these situations, the student is presented specific stimuli at prescribed times which call for observable finite responses, for example, computations based on the present system state, geographic position determinations, or more generally, the performance of tasks where: the antecedent conditions are specifiable, the time of request is specific and the response completion is observable, definable and scorable.

The requirements for presenting and monitoring specific stimuli to the student involve the following:

- trainee station display--Alphanumeric messages are are presented at programed times calling for a specific response from a student.
- trainee station controls--Means must be provided (e.g., keyboard) for the student to respond to a specific message or question.

- a list of messages to be used in conjunction with the lesson plan is provided. This includes the specific content requirements, message length and where in the exercise the message is presented.
- instructor station display of the total list of messages.
- instructor station display of the specific message presented, the student response and an indication of knowledge of results presented.
- immediate supplemental information presented to the student about the results of his performance.
- instructor station controls to call up a programed message--this refers to instructor-initiated messages at times different than programed in the lesson plan.
- student response is automatically compared to the actual situation--the information requirements for programing include, system status information, vehicle position movement and heading, rates of resources expended, etc.

This capability for stimulus control is exemplified in device 1D23, whereby an annunciator panel in the trainee cockpit presents messages which call for specific behaviors from the student (see paragraph 2.3.3.2).

3.4.6.4 Assists for Problem Control. A number of automated features can be incorporated into instructor station design to provide assistance in controlling problem complexity and in unburdening the instructor of certain monitoring and controlling functions in developing instructional strategies for all students. These design options are outlined next.

3.4.6.4.1 Automatic Error Alerts. When a student exceeds a preprogramed error envelope in a training exercise (in terms of the scoring criteria established for the lesson number), a display of this information is provided the instructor and a computer-initiated freeze is the outcome. The performance alert indication is displayed alphanumerically on the CRT when, for example, one error less than the amount preset (e.g., total errors, error class, or error on a given parameter) is accrued. The instructor options are, manual override of the freeze, or accept the freeze with procedures to continue. Controls are required to set in new error tolerance envelopes to continue the exercise. The information requirements include:

- initial scoring criteria for the exercise

- the classes/types of errors to be monitored and scored automatically
- decision rules for the inception of the error alert condition
- continuous alphanumeric display of error information
- new error scoring criteria (△ error change when preset tolerances are exceeded)
- controls for inserting new error criteria (△ error change).

A variation of the automatic error alert mode is provided in device 2F100 (A-7E aircraft). The instructor is able to select ten preprogramed parameters for scoring (from thirty-one possible parameters), each with a defined reference performance criterion (one of five predetermined ranges). The program calculates the actual tolerances for the selected parameters and sets linkages in the simulation programs which trigger indications whenever these tolerance limits are exceeded. Whenever a parameter exceeds its tolerance limit or returns to in-tolerance, the program prints the following data.

- parameter name
- aircraft position (latitude, longitude)
- elapsed time
- direction of the deviation
- reference criterion value

3.4.6.4.2 Individual Parameter Freeze. It is desirable to provide the capability to freeze individual parameters for a given trainee station. For example, in flight simulation, the freezing of the altitude parameter enables the novice pilot trainee to concentrate on heading control. Failure to provide this option may result in the breakdown of performance due to task overloading. The instructor station requires the controls to achieve this and in indication of the parameter freeze on the CRT display. Device 2B24, for example, provides for the following parameter freezes for any trainee station: altitude; attitude; heading; velocity; rate of climb/descent; rotor RPM; torque; turn rate.

3.4.6.4.3 Autopilot Program. A desirable option for flight simulators is the provision of an autopilot program. This program automatically computes ideal or desired vehicle position, rates and rates of change for any programed maneuver or maintains a desired steady state of the vehicle. Such a capability is useful in early phases of training to control task loading, enabling the student to concentrate on other tasks (e.g., comm/nav procedures). The program is also used as a standard against which student performance can be compared and serves in the development of performance scoring values. Co-pilot simulation is provided in device 2B24 to enable the student to perform tasks incompatible with the control of the helicopter. An indicator button at the instructor station activates this capability, including an audio message to the student, via intercom, stating that the aircraft is under co-pilot control. The simulated aircraft flies within the programed tolerances in effect at the time of autopilot initiation, or continues in the steady state condition prevailing at the time of initiation. The same control including an audio message is used to return the device to student control.

3.4.6.4.4 Additional Supports. A closed-circuit television (CCTV) system provides supplemental information for instructional control. A CCTV camera mounted in each trainee station affords the instructor (via a TV monitor) the opportunity to view student control manipulation, the instrument panels and displays (e.g., engine and attitude instruments in flight simulators, signal signatures in EW trainers) and, where pertinent, the correlation of these with an "outside" visual frame of reference (e.g., horizon). The CCTV capability is particularly useful in multi-student training situations involving independent performance where the instructor must time-share among students. The information requirements for this capability include:

- decision on the use of a CCTV monitor in the trainee station
- placement of TV cameras in trainee station(s)
- selection of the type and number of TV monitor(s) in the instructor station
- controls for operating the CCTV system (e.g., camera selection, camera adjustment and positioning, lens adjustment and zoom, selection of the monitor(s) upon which the image is displayed, adjustment of the monitor(s), and display to student(s) (e.g., split lens switches)
- video recording and playback controls.

A video tape recorder provides the playback capability. This unit (with a defined time capacity) accepts the output of a selected trainee station and can be used to play back the video record to any combination of trainee stations and to the instructor station via the TV monitors.

In multi-student trainers, a student data device (e.g., a punched card reader) may be provided in each trainee station to read into the computer the student's identifying and training history data. This information is displayed at the instructor station CRT and is used as data entry information in the automatic selection of a training exercise tailored to the given student's level of achievement. The design requirements include, the content and format of the input (e.g., punched card) and the means for accepting the data for display and for automatic problem selection.

3.4.6.4.5 Knowledge of Results. It should be made explicit that supplementary information about performance provided by equipment or by the computer is a desirable design option and should be implemented whenever feasible. In essence, the feature for design is that providing subsidiary (supplemental, trend) information about performance, 1) enhances student learning and performance, and 2) enhances the monitoring and control capability of the instructor.

In the case of the trainee station, the design goal is to provide augmented feedback of performance information via trainer equipment. This is a special case of information presentation in which the student is provided a signal immediately after responding which indicates how his performance conforms to expectations. Specific design options have already been discussed in paragraph 2.4.4.2 of this report.

Supplementary signals or information have utility also in the instructor station design. Where feasible, the following information requirements are appropriate in technical approach determination.

- alerting signals--this refers to indications that student performance error has exceeded defined criterion limits, or that procedural error has occurred. In the first instance, a continuous display of error information (e.g., alphanumeric format per defined error parameters or classes on a CRT) is provided together with an indication of status, such as a histogram depicting current level of achievement or as a qualitative change in presentation as out-of-tolerance is approached. An example of the second instance is the blinking effect indicating a procedural error of omission or commission on the trainee monitoring system display (see paragraph 3.4.8.2).

- trend information--this refers to indications that a change in status is imminent, for example, a student is approaching an out-of-tolerance condition, and an instructional strategy decision is required from the instructor.

- summary information--this refers to supplementary information on defined, critical aspects or status of performance relevant to the control of instruction.

- static pictorial representations--this refers to the reconstruction (e.g., CRT display) of a segment or the entire sequence of a mission accomplished by a student.

- feedback of overall performance--this involves hard-copy printouts of each student's total performance (in desired formats), available from the computer.

3.4.6.5 Mediation. A valid design alternative concerns the selection of non-equipment options in the technical approach to the device configuration. The term, mediation, denotes this design approach which attempts to reduce or simplify the device hardware and substitute the instructor as an integral part of the training loop. Two aspects are subsumed under this concept: reduction (exclusion) of hardware solutions; and equipment simplification. The value of this approach is obvious in a variety of situations, generally, where instructional support and the information required for performance is quite diverse, depending on student performance (e.g., communications links, ground-controlled approaches (GCA)). There are also more subtle applications where this approach is viable. Suffice it to say, the skillful use of these surrogates for actual equipments may improve the instructional capability by sharpening the focus on the purpose and the objectives of training.

3.4.7 MEASUREMENT SYSTEM DESIGN

The organizing feature in instructor station design as conceptualized in this report is the measurement capability. Knowledge about the outputs of performance provides a basis for assessing the effects of training and for predicting performance under future conditions. In short, performance measurement is the bridge between the student outputs and the information requirements at the instructor station.

Many of the instructional functions described in this section on instructor station design are predicated on an automated monitoring, evaluation and scoring capability. Our discussion centers on automatic human performance monitoring and recording (computer programing and scoring equipment) for providing performance information that can be organized, manipulated and applied to achieve the purpose of instruction. Computer-aided performance measurement is predicated on a number of provisions:

- Continuous automatic evaluation and scoring of each student's performance.

- Preprogramed mission scenarios or lesson plans.

- Measurement routines incorporated in the simulation program to record pertinent events (e.g., parameter deviations) from the preprogramed scenarios. (Automatic data recording pertains only to those situations where specific parameters or events and their tolerance envelopes can be established; the instructor, however, is directly involved in entering data for those situations where no tolerances can be established quantitatively).

- Storage of measures for real-time monitoring, post-exercise printout, and end-of-course program evaluation.

- Evaluation and scoring information available to the instructor via console CRT display and hard copy printout.

- Capability for instructor selection of parameters or events for recording in addition to those inherent in the lesson plan routines.

A number of design decisions must be integrated to achieve an automated monitoring, evaluation and scoring capability. The human factors design issues center on the information requirements involved in the selection of measures, the organization of measurement information, and the display and recording of scoring information. The details that must be resolved are examined next.

3.4.7.1 Selection of What to Measure. Decisions must be made in selecting manageable units of performance, resulting in a listing of things worthy of measurement. Obviously, the types and arrays of measurement possibilities depend on the class of training device and on the training objectives and task structure. This governs the selection of the critical performances for scoring, i.e., emphasis on manual control of vehicles, procedures following, signal detection, decision making, or coordinated team performance. It is assumed that an outline of the task structure and the task analysis has already been accomplished in the M.C. documentation and it is now mostly a matter of correlating skills and knowledge requirements with scores that are relevant and obtainable.

The parameters and events to be sampled describe the interrelations among own vehicle, the target(s) and the media. The parameters recorded relate to classes of data specific to types of training devices. For example, vehicle management parameters are of most importance to flight trainers whereas tactical employment and load (e.g., vehicle units in an engagement) parameters are of significance to tactical team training devices. The relevant parameters reside in the following classes of data.

a. Vehicle management--This class of data refers to vehicle positioning and power plant management parameters. It is of particular importance to flight simulators. For example, the eligible parameters for recording of aircraft performance include the following:

Fixed Wing	Rotary Wing
Heading	Heading
Altitude	Altitude
Airspeed	Airspeed
Pitch angle	Pitch angle
Roll angle	Roll angle
G loading	G loading
Stick longitudinal position	Cyclic stick longitudinal position
Stick lateral position	Cyclic stick lateral position
Rudder position	Collective stick position
Brake pedal position	Rudder position
Trim position	Brake pedal position
Time	Trim position
Vertical velocity	Time
Turn rate	Vertical velocity
Longitudinal stick rate	Turn rate
Lateral stick rate	Cyclic stick longitudinal rate
Rudder rate	Cyclic stick lateral rate
Pitch rate	Collective stick rate

Fixed Wing	Rotary Wing
Roll rate	Rudder rate
Yaw rate	Pitch rate
Engine instruments	Roll rate
RPM	Yaw rate
Torque	Engine instruments
Flight path	Rotor RPM
Flight path deviation	Torque
Approach slope	Flight path
Approach slope deviation	Flight path deviation
	Approach slope
	Approach slope deviation

b. Relative geometry considerations--This class of data is concerned with own-vehicle position and action direction or with an emplaced unit (e.g., carrier aircraft controller) in relation to other units/vehicles in an area of engagement. For example, in surface or subsurface vehicles the important parameters include the variations in range and bearing data (course, speed, depth maintenance or change), and rate of change of these relationships (closing, opening rates, etc.). For a fixed or emplaced unit (GCA or carrier control of aircraft) the parameters of concern include the specific aircraft in relation to the recovery site and the positions and movements among aircraft in a defined pattern.

c. Tactical employment of vehicle--These data refer to the relevant parameters in the basic detection-to-engagement paradigm, involving own vehicle, friendly unit(s) and target vehicle(s). For example, in surface ship ASW training, the relevant parameters inhere in sonar detection and classification, in attack director operations involved in developing the fire control solution, and in certain Combat Information Center operations (e.g., CIC plots) in support of operating the ship as a fighting unit.

d. Load--These data relate to the amount of "clutter" (i.e., number of things) involved in a training situation, and include, the number of different units in an engagement (support units, friendly units, targets), command relationships (HUK forces, SAUs, etc.), and communications requirements.

e. Weapons employment--These data refer to the parameters recorded on weapon selection and preparation and on relevant weapons actions (e.g., water splash point for surface to subsurface missile, torpedo launch and course; countermeasures).

3.4.7.2 Selection of Measures. The measures selected are based on the kind of information desired about the performance. Usually, well-stated training requirements suggest quite easily the corresponding measures and specific performance criteria. One of the problems in programing the computational system is determining what aspects of performance are to be included in the measure. A logical progression is to correlate desired measures and scores with relevant portions of the mission profile. An idea for such a framework is shown in Table 11 which depicts a series of mission-phased measures and appropriate scores for an airborne Electronic Warfare Basic Reconnaissance mission. In addition, some examples from training devices of recent vintage serve to further exemplify the options available.

The design of Device 2-F100 (NTDC 1970) specifies a total of thirty-one parameters to be scored with the means provided the instructor to select no less than ten parameters to be recorded simultaneously for performance evaluation. The total list of parameters is shown below.

- Heading
- Altitude
- Airspeed
- Pitch Angle
- Roll Angle
- G Loading
- Longitudinal Stick Position
- Lateral Stick Position
- Rudder Position
- Throttle Position
- Flaps
- Landing Gear
- Speed Brakes
- Thrust Attenuator
- Elevator Tab Up
- Elevator Tab Down
- Time
- Vertical Velocity
- Turn Rate
- Longitudinal Stick Rate
- Lateral Stick Rate
- Rudder Rate
- Pitch Rate
- Roll Rate
- Yaw Rate
- Engine Instruments
- Canopy Controls
- Seat Controls
- Flight Path and Flight Path Deviation
- Approach Slope and Approach Slope Deviation
- RPM

An organization of these relevant measurement parameters appropriate to the phases in a mission profile is suggested in Table 12 for a mission sequence involving the following: Originate Airfield A, normal takeoff; fly over VOR TAC radio station; proceed on radar navigation leg with enroute malfunctions/emergencies; conduct GCA; normal landing.

For the Air Navigation Trainer, Device 1D23 (NTDC 1971), measurement is conducted for critical navigation parameters and events as defined in the preprogramed lesson plans. Objective measures are obtained as follows:

- Number and duration of tolerance violations by type.
- Bearing and offset error.

TABLE 11. BASIC EW RECONNAISSANCE MISSION MEASURES AND SCORES

Mission Phase	Measure	Scores
Flight planning	N/A	N/A
Pre-flight setup	Switch set-up positions	Sequence of switch positions (checklist format)
		Switch setting error
		Omission of switch setting
		Malfunction correction
		Communications (position of channel switches)
	Equipment preset (bands/frequencies requirements)	Switch positions in equipment preset
	Switch setup per signal	Switch position in search (signal number worked)
		Time to detect (onset/signal to equipment tuned for analysis)
		Cue buildup (onset of signal to search action)
		Switch position in identification (wrong emitter)
		Time to identify
		Signal centering switch positioning
		Time to complete
	Signal setup for DF bearing	Switch position (error)
		Search switch
		Receiver bandwidth

TABLE 11. BASIC RECONNAISSANCE MISSION MEASURES AND SCORES (Continued)

Mission Phase	Measure	Scores
		Attenuator setting, bandwidth path
		Antenna selection (considering polarization tuning)
		ALA-6 cursor position relative to actual bearing
		Time to initiation of DF bearing
		Time to complete
		Re-analyzing the same signal
		Cue buildup between signals
		Number of signals analyzed
	Recording	Time of recording initiation
		Switch position error wafer switch antenna selection audio/recorder level recorder operative
		Correctness of recording (error)
	Analysis	Log keeping (off-line, post-mission)
	Subsequent DF bearing	Time and/or bearing change between DF bearings
		Switch and cursor position error
		Number of DF bearings made per signal
		Total time per signal

TABLE 11. BASIC RECONNAISSANCE MISSION MEASURES AND SCORES (Continued)

Mission Phase	Measure	Scores
	Priority search	Signal attended to per time switch position error
	Threat priority	Time of handling new, higher priority threat
		Switch positions
	General area reconnaissance	Failure to detect/analyze signal
		Total time used per signal
	Evasive maneuvers	Maneuver selection
		Time of initiation
	Malfunction detection/ correction	Detection of equipment malfunction
		Malfunction correction
	Communications	Switch positions on interphone and communications equipments
Post-flight shutdown	Switch shut-down positions	Sequence of switch positions
		Switch setting error
		Communications (position of channel switches)

TABLE 12. SIMULATOR MISSION EXAMPLE

Defined Task Sequences in Mission Profile	Relevant Measures
Pre-start cockpit procedure	Procedure error, trainee monitor system (TMS)
Engine start	Procedure error (TMS)
Pre-takeoff procedures	Procedure error (TMS)
Takeoff	Aircraft attitude, geometry, force/ rate parameters (turn rate, longitudinal and lateral stick rates vertical loading, rudder rate); discrete events (flaps, gear, elevator tabs, power)
Navigation leg (site A to site B)	
Monitor Flight envelope and defined maneuvers	Aircraft attitude, geometry, force/ rate parameters (as pertinent to defined maneuvers); time (to initiate events, to complete event, overall time to activity completion)
Engine fire (emergency)	Procedure error (TMS)
PC1 system failure (emergency)	Procedure error (TMS)
Wing fuel transfer	Procedure error (TMS)
Navigation leg (site B to site C)	
Monitor flight envelope and defined maneuvers	Aircraft attitude, geometry, force/ rate parameters (as pertinent to defined maneuvers); time (to initiate event, to complete event, overall time to activity completion)
In-flight control malfunction (e.g., auto pilot)	Aircraft attitude, geometry, force/ rate parameters (stick rates, rudder, roll, yaw and pitch rates, G-loading); Position of aircraft controls

TABLE 12. SIMULATOR MISSION EXAMPLE (Continued)

Defined Task Sequences in Mission Profile	Relevant Measures
Engine control	Aircraft attitude, geometry, force/ rate parameters; position of aircraft controls; engine instruments
Flame out	Procedure error (TMS)
Surface controls malfunction	Aircraft attitude, geometry, force/ rate parameters; position of aircraft controls
Flight instrument failure (e.g., ADI, roll channel)	Aircraft attitude, geometry force/ rate parameters; position of aircraft controls; speed brakes; engine instruments
Ground controlled approach	Airspeed, flight path, approach slope, vertical velocity, throttle position, rudder, pitch rates, elevator tabs, RPM, engine instruments
Pre-landing check list	Procedure error (TMS)
Landing	Aircraft attitude, geometry, force/ rate parameters
After landing checklist	Procedure error (TMS)
Before engine shutdown checklist	Procedure error (TMS)

- Communication errors.
- Flight change command and flight change accuracy.
- Number of position requests.
- Annunciator-response accuracy and latency (see paragraph 2.3.3.2).
- Variance expressed in standard deviations and percentiles for integrated time and distance about true ground track, time off true ground track, and number of deviations from course. The standard deviations and percentiles reflect the student's performance relative to the ideal criteria and relative standing with other students at the same point in a preprogramed lesson computed accumulatively every half hour.

For the Synthetic Flight Training System (Device 2B24), the performance parameters recorded during the automatic (non-adaptive) mode of operation include:

- Airspeed
- Altitude
- Flight path
- Rate of climb
- Rate of turn
- Pitch attitude
- Bank attitude
- Rotor RPM
- Gas produced RPM
- EGT

In addition, the frequency of procedural error in aircraft control tasks and errors in communication (e.g., tuning the wrong frequency, error in the content of a radio transmission, etc.) is recorded by the instructor. An error button is used to record the time of occurrence of each error perceived by the instructor.

3.4.7.3 Establishing Performance Standards. Various means are available for achieving performance standards. Standards can be set for a number of performances from the rational analysis of the system and task structure. For certain behaviors, adequacy of performance may be differentiated on the basis of time to perform. Reaction time may be critical or error response may be detrimental unless corrected (assuming adequate feedback of performance information) within a short time period after the error response. In other instances, emphasis may be placed on quality and precision of response or on the integration of activities that indicate an ability to cope with a range or unforeseen contingencies.

Another approach to the development of interim standards involves the use of the a priori model of system and vehicle performance which is developed during the design phases of the operational system. The relationships between components as specified in the model can at times be translated into terms allowing a quantitative expression of performance levels required for successful performance.

For more complex performances, the criteria should be based on empirical evidence. Ideally, experiments and actual data collection in the operational setting are desired for establishing the standards. Practically, however, expert opinions are used to establish criteria for successful performance. This intuitive approach is good where standards do not exist or have not been quantified. Interim criteria can be developed in this manner since subject matter experts can provide solid guidance in the development of standards. Also, obtaining repeated scores will allow the development of criteria. For example, continual measurement in the online simulator sharpens the ability to specify required performance levels. The error criteria should be flexible to account for stage of training, and modifiable to enable change as experience with the training program is gained. Thus, initially, tolerances are set intuitively based on previous experience and judgment and are refined as a data base accumulates with experience in the use of the system or as training objectives are modified.

Quite often, useful performance tolerances have been established by the using agency based on much actual experience. This has been particularly the case with flight simulators and the fashion has been to accept performance parameter tolerances based on this expertise. For example, the performance tolerances for the automatic adaptive training mode in Device 2B24 have been set in this way (Table 13).

In other instances, automated evaluation and scoring provides a comparison of student performance with an ideal performance model (with or without a weighting of performance factors). Performance criteria for Device 1D23, for example, are developed from mathematical models of ideal navigator performance represented in the preprogramed lesson plans. The models include a performance corridor in X, Y and Z coordinates and consist of the basic parameter values of the lesson plans, to which constants can be added and varied.

TABLE 13. PERFORMANCE TOLERANCES FOR ADAPTIVE SEQUENCING IN DEVICE 2B24

Performance Parameter	Acceptable Tolerances
Altitude	± 100 feet
Airspeed	± 10 knots
Heading	± 5°
Vertical Speed	± 200 fpm
Rate of Turn	± 1°/sec
Ball Position	± 1/4 ball
Pitch Attitude	± 4°
Roll Attitude	± 5°
Course Deviation	± 1 dot
Glide Slope Deviation	± 1 dot
Torque Pressure	± 4 psi

3.4.7.3.1 Modifying performance criteria--Consideration must be given to the capability for modifying the computer scoring criteria in the software programs. In the case of an error alert whereby the computer halts the problem when a student exceeds the permissable error envelop in terms of the preset scoring criteria established for a particular mission or stage of training, the requirement is to set in new error criteria to establish the next error alert (computer halt) level. This can be accomplished via CRT display (e.g., page(s) of alphanumeric information for error analysis) and appropriate controls (e.g., keyboard, lightpen) to address the computer to override previous error criteria and modify (as required) by inserting new tolerances. This enables the continuation of the exercise according to the training strategy elected by the instructor.

In Device 2F100 (A7-E aircraft), the instructor has the capability to preprogram five different values and ranges of difference for each parameter (i.e., specifying different values for differing problem segments). In addition, the tolerance envelopes for each parameter can be modified (five levels of Δ error) at the console with the problem underway.

3.4.7.4 Sampling of Performance. A major concern in measurement is the quantitative determination of how student performance compares to the ideal or the desired performance for a given circumstance. A most effective means of scoring is to record out-of-tolerance performance, i.e., error deviations in excess of a preset value or envelop. Measurement routines can be incorporated in the simulation program to record parameter deviations from mission parameter profiles (this is the scoring convention in flight simulators). Additional consideration should be given to the following capabilities:

- scoring of procedural performance in terms of errors in sequence and errors of omission in a preset sequence (see paragraph 3.4.8.2).
- recording the performance of critical events (and time of performance) in the lesson plan.
- use of the instructor as a link to the computer for scoring behaviors not easily processed automatically (e.g., communications).

3.4.7.4.1 Data sampling rates--This design consideration concerns such issues as: how often the measurement data are sampled in the training exercise; the length of time each sample is examined; and the places in the mission scenario wherein the sampling is conducted. These scoring decisions are correlated with computer "space availability." Logically, the sampling time for defined tasks (e.g., a 90° level turn at a rate of 3°/sec) is set to include that complete performance; for more or less continuous controlling (e.g., maintaining altitude or heading in turbulence), the sampling time must be based on other logical considerations, derived usually from experience. For example, the SFTS (Device 2B24) is programed to sample performances in ten-second intervals. The question of the reliability of the sampling intervals must be considered carefully in terms of minimum man-system response times and in terms of specific task characteristics (e.g., aircraft roll oscillations of three seconds per cycle should be sampled for several complete cycles per interval). A capability is also desired which enables the instructor to interrogate any single parameter or event at any given time in the mission cycle and receive an indication of the deviation from the reference value of that parameter or event.

3.4.7.4.2 Organizing the measurement data--Since the computer is utilized for scoring, evaluating and recording performance, a word is in order concerning the organization of this information in determining the progress and outcomes of training. Time histories of performance are obtainable as is information on event or status situations due to their binary nature. Frequency data are likewise easily assembled and manual control scores (e.g., integrated error rates) can be quickly computed. Larger segments of performance and terminal (system) outputs are also achievable directly. The computer is able to combine, integrate and weight scores and compare the results against defined error tolerance criteria. Thus, design decisions must concern the following:

- Combining, integrating the performance dimensions/parameters scored.
- Weighting of scores and priority ranking of scored performance for error and situational display at the instructor station.

- Providing feedback of performance information to the student (error presented immediately as accrued, on primary or secondary displays in the trainee station).

3.4.7.5 Display and Recording of Measurement Information. Computer programing is required to 1) monitor the critical aspects of student performance, 2) score all students objectively against standard parameters, 3) relay pertinent performance and error information to instructor console CRT displays, 4) deliver performance cues and performance information to display at each trainee station (for example, augmented feedback of performance information in the form of alphanumeric error indication), and 5) provide a record of performance for all students throughout each mission. The manner in which student performance information is presented at the instructor station is a key human factors input to design.

3.4.7.5.1 Computer-Generated Displays--Computer-generated displays of student performance information include the following information requirements:

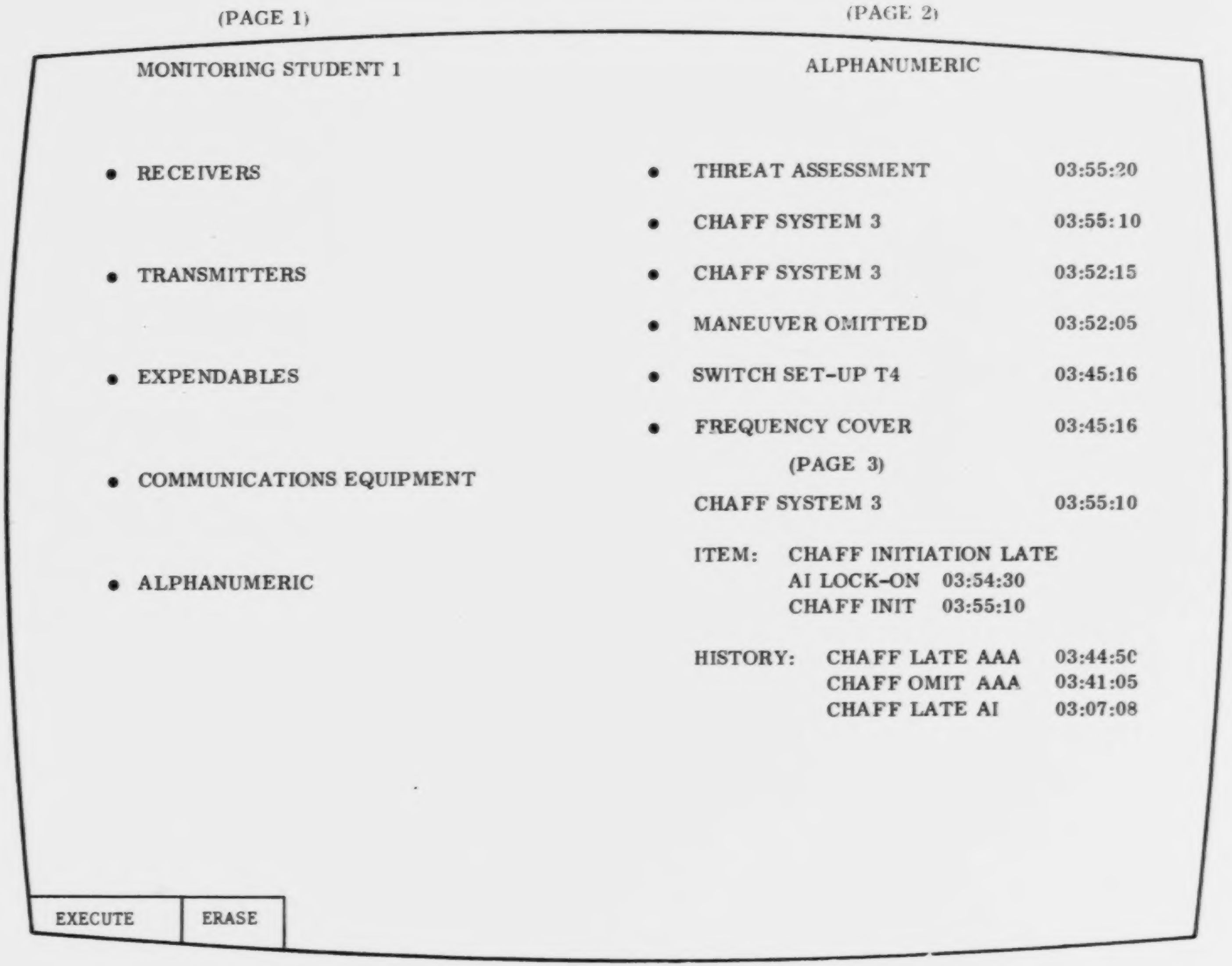
- display of error information and situational information (student performance and system status).
- multi-formatting and successive-page formatting to provide the necessary performance information when required (speed of change and flexibility) for the various instructional modes (monitoring and control, evaluation, demonstration, reinstruction).
- both continuous error indications and the display of error in excess of preset tolerances, as well as performance and status information on-demand.
- CRT displays include both alphanumeric and graphic page formats with associated selection controls (e.g., lightpen, keyboard input devices).
- error alert indication provides an automatic display (and concomitant problem halt) of student error when the error exceeds the limits established for a defined error class(es) or parameter(s).

The CRT display requirements for the measurement of performance vary considerably among classes of training device so much so that the information and formatting details are specific to the device under consideration. Several examples are shown below to provide the reader a sampling from a range of possibilities. Figure 25 shows an error analysis display for the chaff system in an airborne Electronic Warfare simulator. A Graphic Interactive Display (GRID) is shown which consists of an alphanumeric vector CRT display and a lightpen for executing the monitoring and control functions. Figure 26 shows a GRID page format for the error alert mode for the EW system in the previous figure. Figure 27 shows a display of aircraft out-of-tolerance mode proposed for the Air Navigation Trainer (Bark, et al 1969). This shows the preset air lane tolerance band. An aircraft appears on this display whenever it deviates from the established flight path. The aircraft which is most seriously in error is labeled "most critical aircraft" and is identified in a location separate from other errant aircraft. A more detailed discussion of data handling and display requirements is presented in Chapter 3.4.3.

3.4.7.5.2 Hard Copy Computer Outputs--Since the digital computer is capable of recording error deviations and all time and event happenings, a variety of records of student performance may be provided via hard copy printouts. This printout can be to the level of switch activations in the exact sequence of manipulations or indications that parameter envelops have been exceeded. Grosser levels of call-out may also be specified. The record of performance serves two purposes. It is used for mission monitoring (enroute) and for post-exercise critique as a means of controlling the progress and outcomes of instruction. It is also used for school record-keeping and for developing a normative data base of performance information. (The concern for quality control in the production of trained personnel is a legitimate issue for design. Measurement data provide the basis for determining the quality level of the student population trained in the device.) The formatting requirements for retrievable hard copy depend on the information desired and how it must be combined and used. The formats should satisfy the following:

- out-of-tolerance errors--Printouts are provided whenever the value of a particular parameter exceeds the preset range of allowable parameter deviation. This includes, the elapsed time at which the parameter(s) deviation occurred and when a return to within-tolerance is achieved; or the identification of all critical deviations, the problem time, response, event or position in a maneuver.

- time and event printouts-- These present the total performance record, and are used both for critique and for school record-keeping functions. An additional use is in evaluation (checkride) missions where detailed indications are desired on the progress and outcome of the mission.


(PAGE 1)

MONITORING STUDENT 1

- RECEIVERS
- TRANSMITTERS
- EXPENDABLES
- COMMUNICATIONS EQUIPMENT
- ALPHANUMERIC

(PAGE 2)

ALPHANUMERIC

● THREAT ASSESSMENT	03:55:20
● CHAFF SYSTEM 3	03:55:10
● CHAFF SYSTEM 3	03:52:15
● MANEUVER OMITTED	03:52:05
● SWITCH SET-UP T4	03:45:16
● FREQUENCY COVER	03:45:16

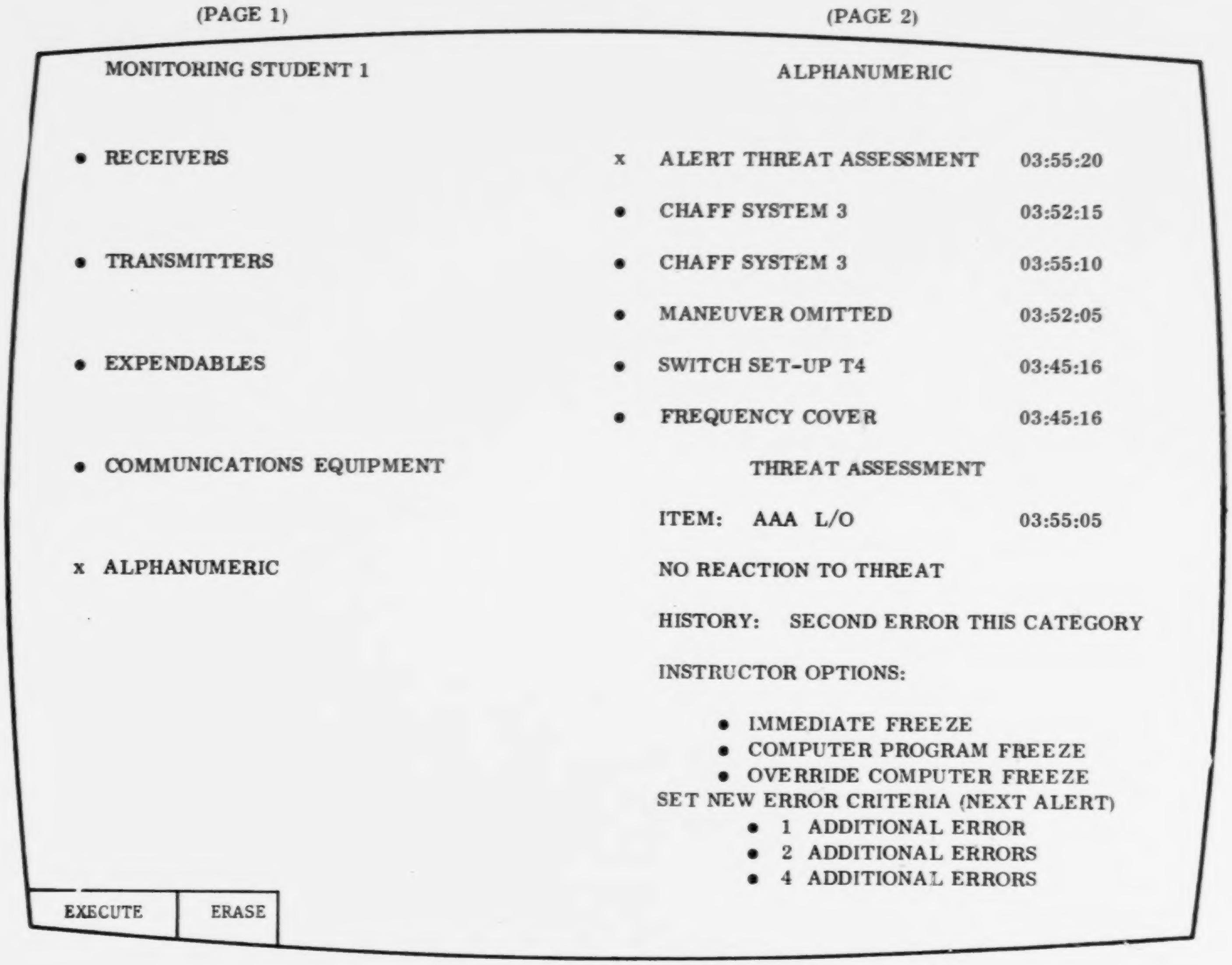
(PAGE 3)

CHAFF SYSTEM 3 03:55:10

ITEM: CHAFF INITIATION LATE
AI LOCK-ON 03:54:30
CHAFF INIT 03:55:10

HISTORY: CHAFF LATE AAA 03:44:5C
CHAFF OMIT AAA 03:41:05
CHAFF LATE AI 03:07:08

Figure 25. CRT Page Format for Error Analysis, Chaff System.



(PAGE 1)

MONITORING STUDENT 1

- ● RECEIVERS
- ● TRANSMITTERS
- ● EXPENDABLES
- ● COMMUNICATIONS EQUIPMENT
- x ALPHANUMERIC

(PAGE 2)

ALPHANUMERIC

x	ALERT THREAT ASSESSMENT	03:55:20
●	CHAFF SYSTEM 3	03:52:15
●	CHAFF SYSTEM 3	03:55:10
●	MANEUVER OMITTED	03:52:05
●	SWITCH SET-UP T4	03:45:16
●	FREQUENCY COVER	03:45:16

THREAT ASSESSMENT

ITEM: AAA L/O 03:55:05

NO REACTION TO THREAT

HISTORY: SECOND ERROR THIS CATEGORY

INSTRUCTOR OPTIONS:

- ● IMMEDIATE FREEZE
- ● COMPUTER PROGRAM FREEZE
- ● OVERRIDE COMPUTER FREEZE

SET NEW ERROR CRITERIA (NEXT ALERT)

- ● 1 ADDITIONAL ERROR
- ● 2 ADDITIONAL ERRORS
- ● 4 ADDITIONAL ERRORS

Figure 26. CRT Page Format for Error Alert Mode.

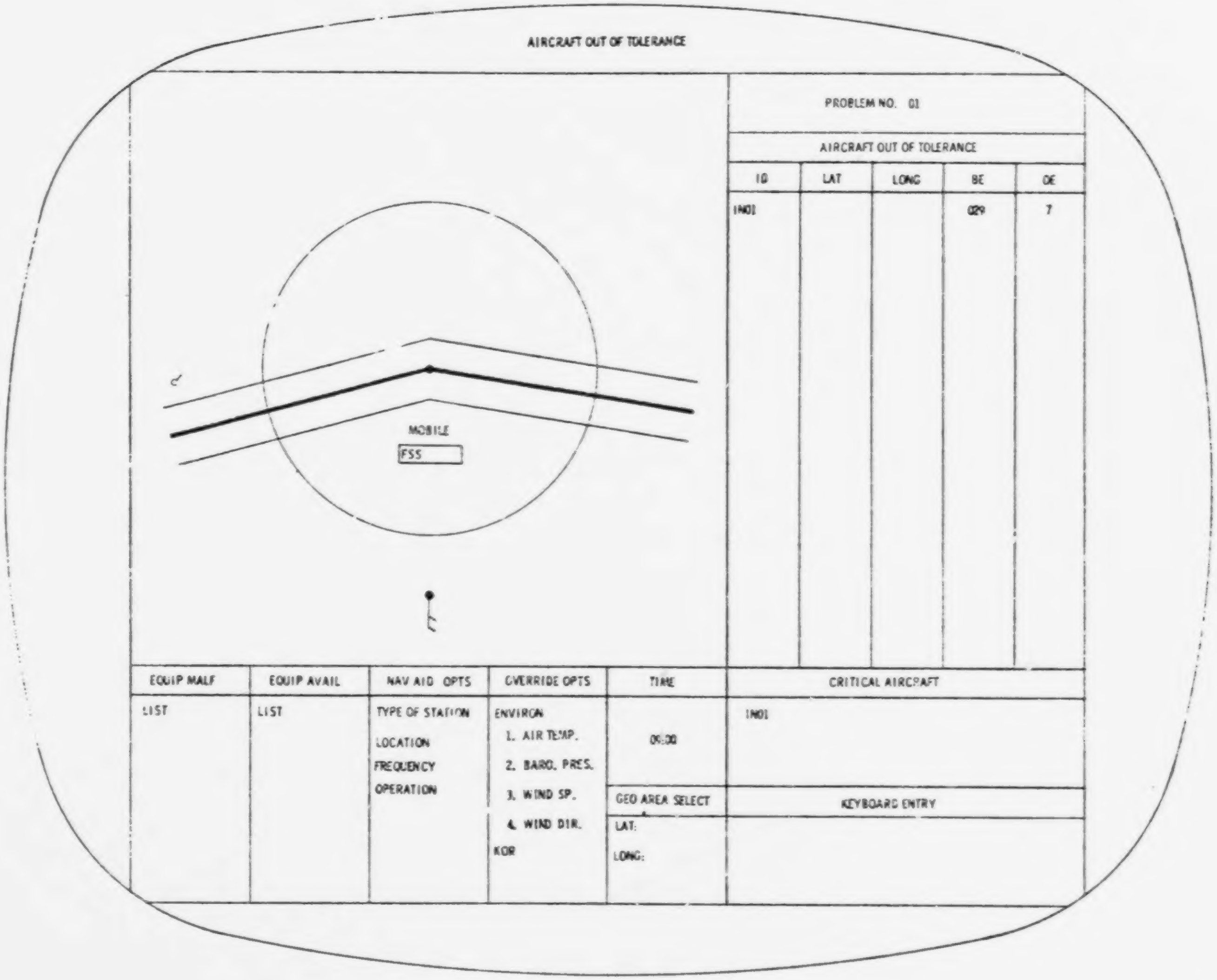


Figure 27. Aircraft Out-of-Tolerance Mode.
(From Bark, et al 1969)

- total error printouts--These are complete error printouts across mission time and are used for critique of training. Error indications are presented by classes and trends of errors are identified.

- summaries of error scoring--These are also used for critique purposes, in the instructional sense, since they represent short summaries of errors made per error class, scores achieved per mission segment, total score for the mission, etc. The value of this type of single-page summary per mission is that a file can be kept simply on each student which is useful in diagnosing performance error and for trend depiction.

The information and the formatting requirements for hard copy records of performance are discussed in detail in Chapter 3.4.13 dealing with post-exercise capabilities.

Controls must be provided for instructing the hard copy printer to provide particular records on demand. For example:

- to provide a summary of out-of-tolerance parameters during the training exercise, such information being keyed to the out-of-tolerance information being displayed on the CRT.

- to provide a record of the most recent procedural task or the one in progress.

3.4.7.6 Some Additional Considerations.

3.4.7.6.1 Conditions Under Which to Measure Performance--Once the measurement requirements have been determined, the task conditions under which performance is measured must be specified. As with the tasks themselves, the conditions under which performance is observed will necessarily represent a sampling of the anticipated real conditions. In selecting the sample of conditions that will prevail, two general rules should be considered:

- Those conditions should be selected which are known (or suspected) to have the greater influence on performance.

- Within those conditions selected, the extremes or limits anticipated should be included.

Task conditions are independent of what measures will be used (i.e., decide on what measurements are desired, then determine the conditions). The conditions of measurement, however, do influence when the measurements will be taken and in some instances how often the measures will be repeated. For example, when load conditions vary in a mission sequence, it may be appropriate to take measurements at selected points in order to indicate system status or performance at these times.

Emphasis must be placed on the standardization of test conditions and environments. Not only should measures be standard (used in similar ways with the same meaning by the personnel involved) but also, the general environment in which the measurement is to be taken should be standard. Adherence to this insures that measures will be strictly comparable from one student or team to another and from one time to another.

Two types of variations in the conditions under which performance can be observed are apparent. These are, task conditions and environmental conditions. Measurement should be conducted under a variety of task loadings representative of those which may be or are encountered in operations. Task loading should be systematically manipulated to induce stress evoked by situations requiring unusual or complex decisions and emergency situations which give rise to additional task demands.

It is important also to conduct measurement under the more important environmental conditions. These include: acceleration forces, movement about axes, sound and vibration, temperature extremes, and the range of visual conditions. In order to provide the selected conditions in a uniform manner throughout training and measurement, design should provide for calibration of the simulated environment.

3.4.7.6.2 Quality Control--The recording of student performance and error information for off-line record-keeping analysis (for all students in a course) with a program for the analysis of such information, is a desirable capability in a training device. For example, programing could be written to permit the recording of classes of students, performances of students assigned to given instructors, performances of students compared to the total (cumulative) student norm, etc. With this data base, deficiencies in instruction may be efficiently identified, thus facilitating needed revisions. Cumulative student data enables the development of a normative data base for quality control in instruction.

An example of automatic quality control of training data is provided by the Synthetic Flight Training System (Device 2B24). An automatic quality control of training-data processing program is specified which accepts as inputs, the checkride performance data together with the identification of each student, his training group and flight instructor and other descriptive data for comparing the performance of groups. The program output data is in hard copy graph form, showing the frequency and cumulative time of error for various sortings (e.g., by student class, by instructor, etc.) for the following:

- for each maneuver comprising the checkride (e.g., ILS, ADF approach, GCA, instrument takeoff, et al).
- for each parameter identified for scoring without respect to maneuver.
- for each parameter separately by checkride maneuver.

Each graph contains separate plots of the same data for at least one comparison group (e.g., the cumulative corresponding data for a preceding student group) which may be identified as the reference standard. The program includes an indication of the statistical significance of any deviation in performance between the group under examination and the comparison group. The program is run off-line.

3.4.8 PROCEDURAL PERFORMANCE--DISPLAY AND RECORDING

A desirable instructional feature is the capability for real-time monitoring and evaluation of student procedural (checklist) performance. This is another automated performance measurement technique which provides an assessment capability for instructor use in developing effective training strategies. It is relevant to situations requiring substantial amounts of procedures-following behavior involving both normal and emergency sequences. At present, this type of measurement capability is most appropriate to flight simulators and serves as a means for a display and control of checklist procedural performance (for example, as defined in the NATOPS flight manual for the design basis aircraft).

The displays and controls for achieving this computer monitoring of checklist events include the following.

- CRT display for presenting the procedures to be accomplished and student performance data in a single integrated display.
- keyboard control input to the computer for direct writing on the CRT display. The keyboard provides an alphanumeric code with the requisite number of displayable characters.
- programable keyfield to transmit control function codes to the computer as selected by the instructor. Coded overlays are required for insertion into the keyfield.
- display generator for accepting computer and keyboard inputs and for driving the display.
- hard copy printout available of the procedural performance for debriefing and for school record-keeping.

3.4.8.1 Design Basis. The information requirements that must be satisfied to achieve this capability involve the following classes.

3.4.8.1.1 Modes of Operation--Several modes of operation are required to employ this subsystem both enroute during the exercise and offline (pre- and post-mission phases).

- problem mode--This is the enroute exercise mode which provides for the monitoring of student checklist activities, controlling the procedural sequencing (start, stop, reset, procedural repeat), and recording student procedural performance for subsequent display and debriefing.

- edit mode--This is an off-line mode which enables the adding, deleting and changing the sequence of steps in a procedure(s).
- daily readiness check program--This is an off-line mode for monitoring and controlling the checkout of the training device.
- replay mode--This is an off-line mode for calling up a hard copy of the printout of the stored data for debriefing.
- inspect and change memory locations mode--This is an off-line mode which provides the means for inspecting and changing all memory locations in the main trainer computer and for requesting a hard copy code dump of all changes made.

3.4.8.1.2 Procedures To Be Trained--The representative list of procedures that will be installed for training (both normal and emergency) are identified together with the step sequences for each procedure.

3.4.8.1.3 Display Presentation--The following classes of information must be accounted for.

- display format--This includes: the procedure title; the sequence of steps for each procedure; the number of pages or half-pages for each procedure; the number of trials for each defined checklist sequence; out-of-sequence page number (for the page not in current view); and preview area for alphanumeric keyboard entries.
- display density--This defines the number of characters (alphanumeric) and format that describe the most complex display (number of lines and number of characters per line).
- a selective blinking feature serves to indicate errors of omission or commission to the instructor.
- cursor--This is the means for positioning the inputs from the keyboard and for erasing errors.
- display characteristics--This includes size, shape, location, refresh rate and resolution (as an input for engineering definition of type of display, e.g., TV monitor, and character generation technique).

- controls--This refers to the keyboard requirements for instructor inputs, e.g., special keyboards (alphanumeric and functions); keyboard coding, number of keys and layout; keyboard usage per operational mode.
- overlay design--This is provided for each operational mode.

3.4.8.2 Design Example: Trainee Monitoring System. An example of a design for real-time monitoring and evaluation of trainee procedural performance is provided next. This is the Trainee Monitoring System (TMS) proposed for Device 2F100, simulating the A-7E aircraft (NTDC 1970). The TMS provides an additional data source for promoting objective instruction and performance evaluation. The procedures-following sequences during ground and inflight operations are computer monitored and student procedural performance (errors of omission and commission in procedural checks) is displayed at the instructor console.

A proposed CRT display system consists of a display generator, a TV monitor, an alphanumeric keyboard and a programable keyfield (overlays). The TMS is an interactive display system providing the following modes of operation.

- PROBLEM mode--Enroute monitoring of student action and the control of data storage for replay.
- EDIT mode--Off-line call up and modification of procedures.
- DRED mode--Off-line monitor and control of the daily readiness check program.
- REPLAY mode--Off-line call up of stored procedures for debriefing.
- INCH mode--Off-line inspection and change of memory locations.

The TMS capability enables the instructor to perform the following:

- start, stop and reset the training problem.
- edit operational procedures, adding, changing and deleting the specified procedural steps.
- monitor and evaluate student performance.

- record student performance for later replay and for debriefing.
- monitor and control the daily readiness check program.
- inspect and change memory locations.

The specifics which follow pertain to the structuring and controlling of procedural training during an actual exercise (i.e., operating in the PROBLEM mode). An analysis of the procedures specified in the NATOPS flight manual for the A-7E aircraft (NAVAIR 01-45-AAE-1) indicates a total of 31 normal and emergency procedures pertinent to the present training situation. Table 14 lists these procedures. Of this total, the "prestarting cockpit procedures" exceeds all others in the number of steps required in the sequence (57 steps) and thus is utilized as a basis for organizing the display presentation (i.e., most complex case).

3.4.8.2.1 Display Format--Four independent displays are generated to accommodate all operational modes. Each display has the following characteristics.

- total number of characters or symbols - 3456
- characters or symbols per line - 72
- number of lines - 48
- blink--character selectable
- white-on-black and black-on-white characters
- character and symbol set--95, including graphics
- cursor
- refresh rate, 50 fields per second

Each checklist procedure is considered as a display format. Each format is organized into half-page displays with each display consisting of 15 steps. The first and second half-pages of a format are displayed simultaneously in the upper and lower halves of the CRT. Upon completion of the first half-page of a procedure, the second half-page will replace it at the top of the display (automatically or manually via keyboard) and a third half-page will fill the lower half of the display. This is repeated until all steps of a procedure are completed, at which time the next procedure in sequence is automatically called up, unless overridden by the instructor.

The format of the display presentation (PROBLEM mode) is shown in Figure 28. The normal prestarting cockpit procedure (57 steps) provides the example. The displayed information is as follows:

TABLE 14. NORMAL AND EMERGENCY PROCEDURES FOR A-7E AIRCRAFT (NATOPS FLIGHT MANUAL NAVAIR 01-45-AAE-1)

1. Prestarting cockpit procedures -maximum of 57 steps - normal procedure.
2. Engine start ground - maximum of 10 steps - normal procedure.
3. Pre-takeoff - maximum of 15 steps - normal procedure.
4. Pre-landing - maximum of 13 steps - normal procedure.
5. Ejection (primary and secondary) - maximum of 13 steps - emergency procedure.
6. Engine fire ground - maximum 5 steps - emergency procedure.
7. Engine fire flight - maximum 5 steps - emergency procedure.
8. Refueling (inflight) - maximum 14 steps - normal procedure.
9. Fuel control failure - maximum 5 steps - emergency procedure.
10. Fuel boost pump failure (single pump and pumps 1 and 2) 1 step and 3 steps - emergency procedure.
11. Wing fuel transfer - 2 steps - normal procedure.
12. Wing fuel transfer failure - maximum 3 steps - emergency procedure.
13. Master generator failure - maximum 4 steps - emergency procedure.
14. Pitch trim failure - maximum 6 steps - emergency procedure.
15. Roll trim failure - maximum 3 steps - emergency procedure.
16. PC1 System failure - maximum 8 steps - emergency procedure.
17. PC2 System failure - maximum 8 steps - emergency procedure.
18. PC3 System failure - maximum 8 steps - emergency procedure.
19. PC1 and PC2 failure - maximim 9 steps - emergency procedure.

TABLE 14. NORMAL AND EMERGENCY PROCEDURES FOR A-7E AIRCRAFT (NATOPS FLIGHT MANUAL NAVAIR 01-45-AAE-1)(Continued)

20. PC1 and PC3 failure - maximum 11 steps - emergency procedure.

21. PC2 and PC3 failure - maximum 11 steps - emergency procedure.

22. Canopy jettison - maximum 4 steps - emergency procedure.

23. Instrument Check list - maximum 17 steps - normal procedure.

24. After landing - maximum 8 steps - normal procedure.

25. Before engine shutdown - maximum 7 steps - normal procedure.

26. Engine shutdown - maximum 3 steps - normal procedure.

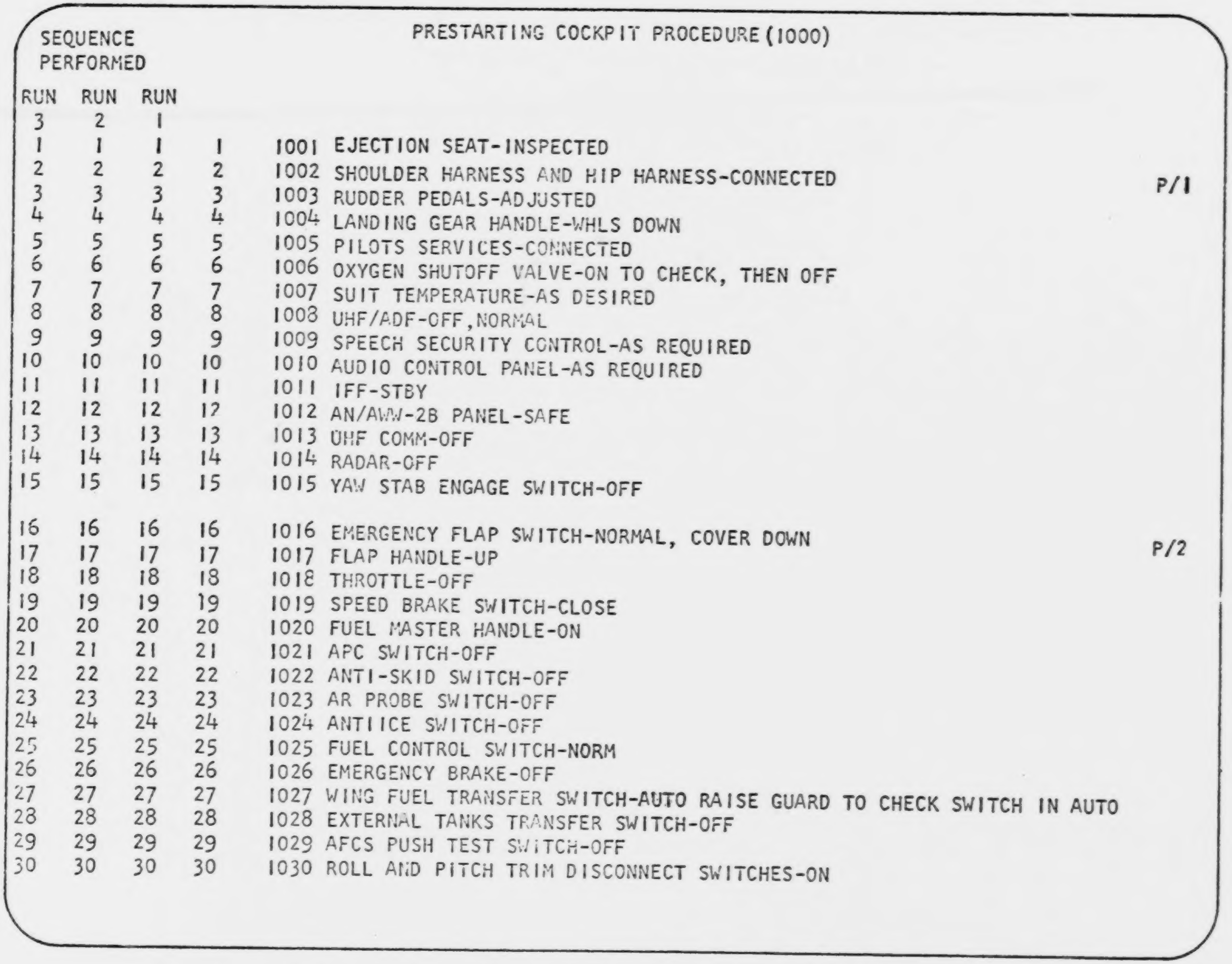
27. Before leaving aircraft - maximum 3 steps - normal procedure.

28. Taxi - maximum 9 steps - normal procedure.

29. Before takeoff - maximum 16 steps - normal procedure.

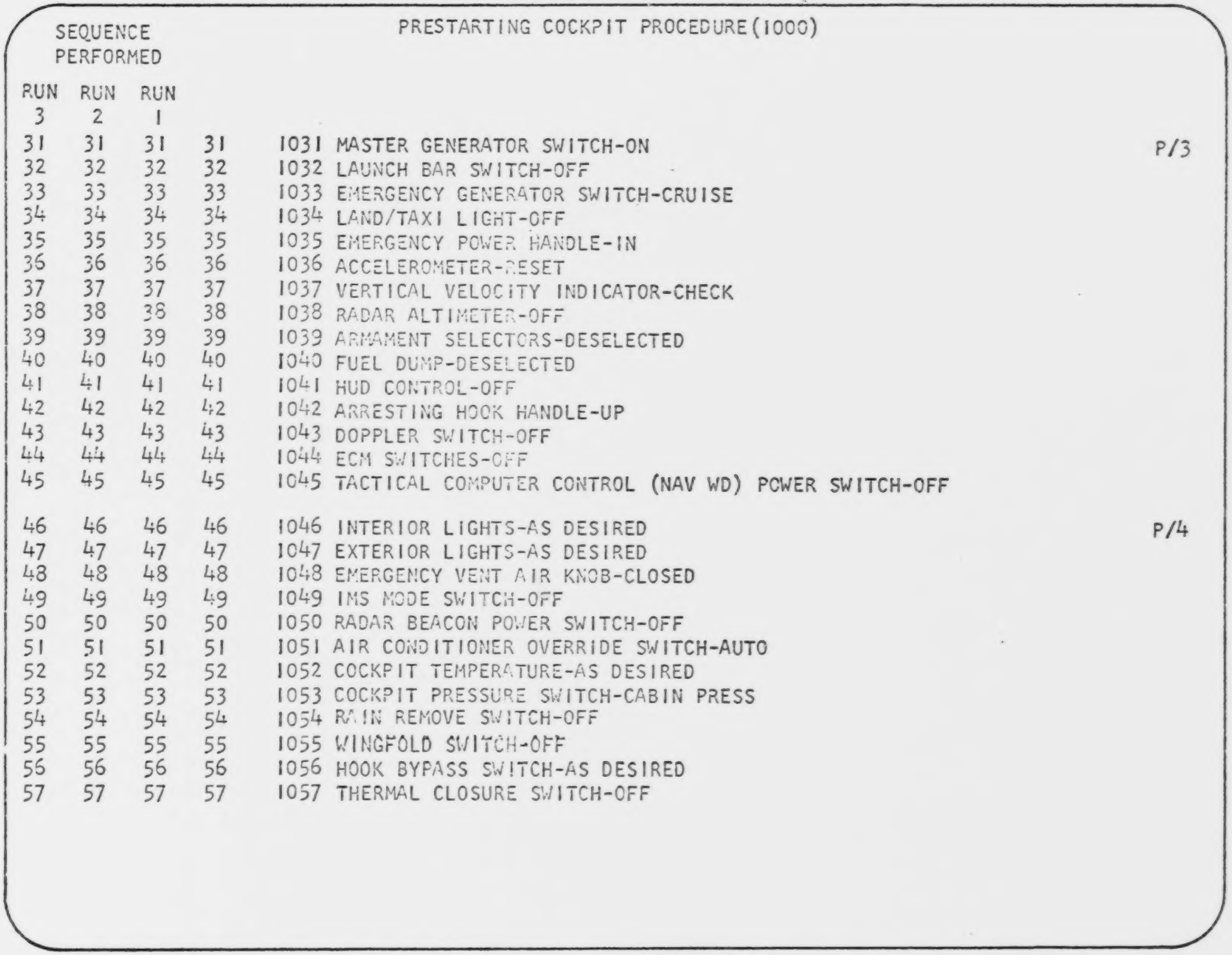
30. Flameout - maximum 19 steps - emergency procedure.

31. Speed brake failure to retract - maximum 4 steps - emergency procedure.



SEQUENCE PERFORMED				PRESTARTING COCKPIT PROCEDURE (1000)		
RUN 3	RUN 2	RUN 1				
1	1	1	1	1001	EJECTION SEAT-INSPECTED	
2	2	2	2	1002	SHOULDER HARNESS AND HIP HARNESS-CONNECTED	P/1
3	3	3	3	1003	RUDDER PEDALS-ADJUSTED	
4	4	4	4	1004	LANDING GEAR HANDLE-WHLS DOWN	
5	5	5	5	1005	PILOTS SERVICES-CONNECTED	
6	6	6	6	1006	OXYGEN SHUTOFF VALVE-ON TO CHECK, THEN OFF	
7	7	7	7	1007	SUIT TEMPERATURE-AS DESIRED	
8	8	8	8	1008	UHF/ADF-OFF,NORMAL	
9	9	9	9	1009	SPEECH SECURITY CONTROL-AS REQUIRED	
10	10	10	10	1010	AUDIO CONTROL PANEL-AS REQUIRED	
11	11	11	11	1011	IFF-STBY	
12	12	12	12	1012	AN/AWW-2B PANEL-SAFE	
13	13	13	13	1013	UHF COMM-OFF	
14	14	14	14	1014	RADAR-OFF	
15	15	15	15	1015	YAW STAB ENGAGE SWITCH-OFF	
16	16	16	16	1016	EMERGENCY FLAP SWITCH-NORMAL, COVER DOWN	
17	17	17	17	1017	FLAP HANDLE-UP	P/2
18	18	18	18	1018	THROTTLE-OFF	
19	19	19	19	1019	SPEED BRAKE SWITCH-CLOSE	
20	20	20	20	1020	FUEL MASTER HANDLE-ON	
21	21	21	21	1021	APC SWITCH-OFF	
22	22	22	22	1022	ANTI-SKID SWITCH-OFF	
23	23	23	23	1023	AR PROBE SWITCH-OFF	
24	24	24	24	1024	ANTIICE SWITCH-OFF	
25	25	25	25	1025	FUEL CONTROL SWITCH-NORM	
26	26	26	26	1026	EMERGENCY BRAKE-OFF	
27	27	27	27	1027	WING FUEL TRANSFER SWITCH-AUTO RAISE GUARD TO CHECK SWITCH IN AUTO	
28	28	28	28	1028	EXTERNAL TANKS TRANSFER SWITCH-OFF	
29	29	29	29	1029	AFCS PUSH TEST SWITCH-OFF	
30	30	30	30	1030	ROLL AND PITCH TRIM DISCONNECT SWITCHES-ON	

Figure 28. Normal prestárting cockpit procedure data display. (Part 1 of 2)



```
  SEQUENCE                          PRESTARTING COCKPIT PROCEDURE(1000)
  PERFORMED

RUN  RUN  RUN
 3    2    1
31   31   31   31     1031 MASTER GENERATOR SWITCH-ON                                    P/3
32   32   32   32     1032 LAUNCH BAR SWITCH-OFF
33   33   33   33     1033 EMERGENCY GENERATOR SWITCH-CRUISE
34   34   34   34     1034 LAND/TAXI LIGHT-OFF
35   35   35   35     1035 EMERGENCY POWER HANDLE-IN
36   36   36   36     1036 ACCELEROMETER-RESET
37   37   37   37     1037 VERTICAL VELOCITY INDICATOR-CHECK
38   38   38   38     1038 RADAR ALTIMETER-OFF
39   39   39   39     1039 ARMAMENT SELECTORS-DESELECTED
40   40   40   40     1040 FUEL DUMP-DESELECTED
41   41   41   41     1041 HUD CONTROL-OFF
42   42   42   42     1042 ARRESTING HOOK HANDLE-UP
43   43   43   43     1043 DOPPLER SWITCH-OFF
44   44   44   44     1044 ECM SWITCHES-OFF
45   45   45   45     1045 TACTICAL COMPUTER CONTROL (NAV WD) POWER SWITCH-OFF

46   46   46   46     1046 INTERIOR LIGHTS-AS DESIRED                                    P/4
47   47   47   47     1047 EXTERIOR LIGHTS-AS DESIRED
48   48   48   48     1048 EMERGENCY VENT AIR KNOB-CLOSED
49   49   49   49     1049 IMS MODE SWITCH-OFF
50   50   50   50     1050 RADAR BEACON POWER SWITCH-OFF
51   51   51   51     1051 AIR CONDITIONER OVERRIDE SWITCH-AUTO
52   52   52   52     1052 COCKPIT TEMPERATURE-AS DESIRED
53   53   53   53     1053 COCKPIT PRESSURE SWITCH-CABIN PRESS
54   54   54   54     1054 RAIN REMOVE SWITCH-OFF
55   55   55   55     1055 WINGFOLD SWITCH-OFF
56   56   56   56     1056 HOOK BYPASS SWITCH-AS DESIRED
57   57   57   57     1057 THERMAL CLOSURE SWITCH-OFF
```

Figure 28. Normal prestarting cockpit procedure data display. (Part 2 of 2)

- procedure title.
- all procedural steps in sequence of accomplishment.
- procedure half-page number (2 half-pages per display)
- out-of-sequence half-page number for out-of-sequence step performed on the half-page not in view.
- preview area for alphanumeric keyboard entries.
- numerical character blinking when out-of-sequence step occurs
- three sets of "sequence performed" step numbers (instructor has the capability to repeat a procedure a maximum of 3 times)

3.4.8.2.2 Controls--Instructor call up of a particular procedure is initiated through a function keyboard containing 32 keys. These keys together with coded overlays are used to control the TMS in PROBLEM, EDIT, REPLAY, INCH and DRED modes. A capability for up to 16 overlays is provided. Inserting an overlay will automatically select the pertinent operational mode. For the PROBLEM mode, a function keyboard overlay provides the following functions:

- procedures (a maximum of thirty-five requiring multiple overlays)
- procedure advance (manual or automatic)
- half-page advance
- start
- reset
- store
- replay
- blinking control

An alphanumeric keyboard provides a serial binary code for decoding and direct writing on the CRT TV monitor. The standard alphanumeric repertoire of 26 alphabetical and 10 numerics plus special symbols for identifying or coding procedural steps is provided. Control keys for cursor deployment are also included.

3.4.9 CAPABILITY AND CONTROLS FOR INPUTS TO THE COMPUTER

Means are required for inserting instructions to the computer to achieve the desired CRT display outputs relative to the structure and control of training. The criteria for determining the design of manual input devices are based on the compatibility of the candidate choices with the software programing. Specifically, this concerns the compatibility with a variety of tabular and graphic display formats, flexibility of usage and speed of change in information display, efficiency of panel space usage, and ease of training the instructor in its usage.

Our discussion centers on keyboard design since this at present is the conventional device selection for the manual input capability, although the use of the lightpen is a desirable design option.[1] Various purposes are served by this inputting means, both off-line and on-line including scenario or problem generation/modification, enroute problem control, student performance record editing, and trainer maintenance.. Two basic kinds of keyboard serve the various data entry purposes.

- alphanumeric keyboards serve as the primary means of communication between the instructor and the computer relative to the structure, control and modification of the training and the simulation conditions.
- function keyboards serve in the selection of defined trainer operating modes (primary trainer control means) during the course of an actual training exercise. The function keyboard is also utilized as the primary means of control for the trainee monitor system (PROBLEM, EDIT, DRED, INCH and REPLAY modes--see Chapter 3.4.8).

The information requirements that must be satisfied in the design of manual input devices for accessing the computer include the following:

- the general and specific functions (on-line and off-line to be served by the input device(s).
- the display modes associated with the input device(s).
- keyboard(s) size and placement on the instructor console.

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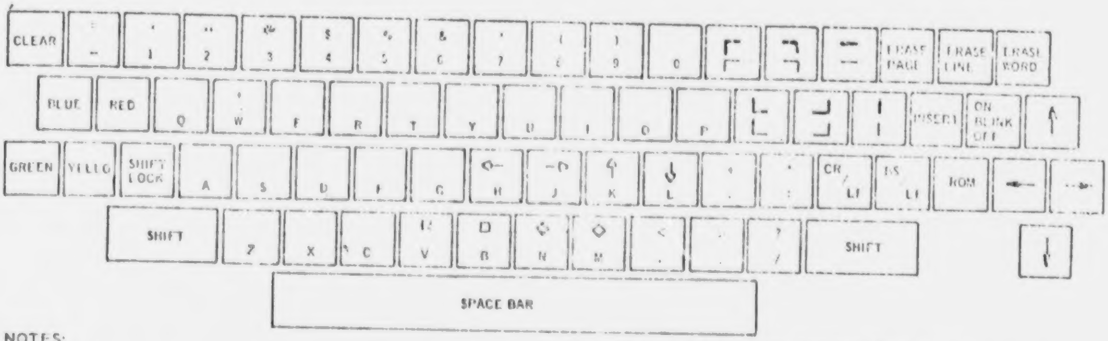
[1] Graphic interactive displays consisting of an integrated-circuit controller, an alphanumeric vector CRT display and a lightpen have been designed for executing the monitor and control functions at the instructor console. This is an effective means for displaying student performance data and mission information to the instructor and for providing the required control for instructional actions.

- alphanumeric keyboard design--Number of keys (alphanumeric and functions), key layout (e.g., standard typewriter layout), key size and color coding.
- function keyboard design--Definition of functions, coded overlay capability for all problem modes.
- electronic interlock requirements (error correction, simultaneous depression of two keys, keyboard lockout of a channel during computer I/O with that channel).
- speed of operation.
- definition of operational sequences.

3.4.9.1 Design Example. An example of manual input device requirements is the keyboard design proposed for an operational flight trainer (Device 2F100, Goodyear 1971). An alphanumeric and a functions keyboard are specified. The alphanumeric keyboard is equipped with 48 alphanumeric keys and 21 function keys. A standard typewriter layout is employed and the necessary electronic interlocks are provided to prevent garbling of codes when two or more keys are depressed simultaneously and to lock out the keyboard from a channel during computer I/O with that channel. The 21 function keys serve the following: insert, space bar, erase page, carriage return and line feed, word erase, cursor positioning (4 positions), color code (4 optional codes), blink, home, erase-line, backspace and line feed, clear, shift, shift lock and repeat. The alphanumeric keyboard layout is shown in Figure 29.

The performance specifications for the training device also call for a thirty-two key function keyboard, with special coded overlays for the PROBLEM, EDIT, DRED, INCH and REPLAY modes. An example of the overlay for the PROBLEM mode is shown in Figure 30. To enable the instructor to access quickly all pertinent data and make problem changes according to student actions, two overlays are provided (i.e., to accommodate two sets of procedures). Each overlay has eight common functions and four unused keys. The keyboard design reflects the following:

- The less a key is used, the nearer to the back and right of the keyboard it is placed.
- If a function is used on more than one overlay, the same key is used.
- Associated functions are placed in rows.



NOTES:

1. KEYS ARE ON 3/4 IN. CENTERS
2. REPEAT FUNCTION IS INCORPORATED INTO EACH KEY, THAT IS, CONTINUOUS DEPRESSION OF A KEY CAUSES THAT KEY'S FUNCTION TO BE REPEATED, AFTER A SLIGHT PAUSE, AT A RATE OF 10 CHARACTERS PER SECOND
3. CLEAR, ERASE PAGE, ERASE LINE, AND ERASE WORD FUNCTIONS REQUIRE A SIMULTANEOUS ACTIVATION OF THE SHIFT FUNCTION
4. KEYS THAT HAVE TWO ENGRAVED LEGENDS, INCLUDING THE BLINK KEY, REQUIRE A SIMULTANEOUS SHIFT FUNCTION FOR THE TOP LEGEND
5. KEYBOARD COLORS:
   - A. ALPHANUMERIC AND STANDARD KEYS - GREY WITH WHITE LEGENDS
   - B. COLOR KEYS - CORRESPOND COLOR, I.E., RED, GREEN, YELLOW, BLUE - NO LEGENDS REQUIRED
   - C. OTHER FUNCTION KEYS AND BLACK WITH WHITE LEGENDS

Figure 29. Alphanumeric keyboard.

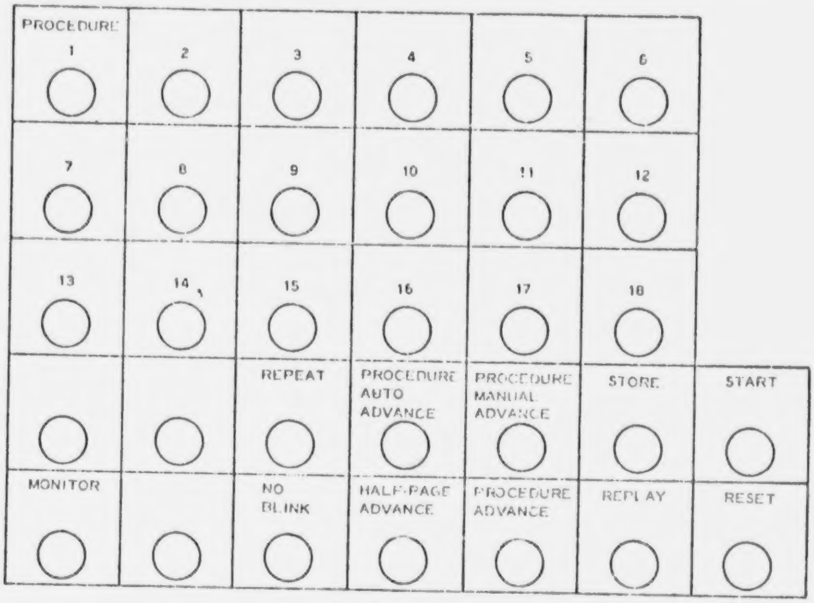


Figure 30. Overlay, PROBLEM mode.

- The sequence of events begins at the bottom row of keys and works up.
- No more than two keys will be used to access a function.
- Lights are incorporated in the keys to indicate the function being processed.
- Inserting the overlays will automatically select PROBLEM, EDIT, REPLAY, DRED and INCH modes.

3.4.10 SOFTWARE CAPABILITY FOR DEVELOPING AUTOMATED ADAPTIVE STRATEGIES

The emphasis on machine or computer control in the development of the training capability places severe requirements on the software programing. Computer programing is the means for formalizing the decision logic tailored to student performance based on a responsive monitoring, evaluation and scoring capability.

Automatic adaptive sequencing as a technique for programing the computer is a new approach for training device design and not much data are available for design use. Adaptive simulation is a difficult undertaking from the standpoint of instructional validity, and at this time, many problems and issues must be resolved before firm guidelines can be established for implementing this technique. Although *our purpose in this report is not to stress the inadequacies in design data*, it must be made clear that inherent difficulties exist in implementing an automatic adaptive system that will satisfy the instructional expectations. This prologue is thus warranted to place the material which follows in perspective.

3.4.10.1 Adaptive Simulation as a Design Option. Perhaps the significant question for design concerns the efficacy of adaptive simulation for training. Although a number of interesting relationships have been demonstrated in the laboratory, no substantial assessments are available which evaluate the effectiveness of adaptive simulation as a practical training method for producing the skills required in the operational environment. However, it is not difficult to favor adaptive training as a concept since logically all training is (ideally) adaptive. Hence, many theoretical advantages inhere in adaptive simulation. As a technique for presenting information to the student it has made explicit a number of features that are intuitively desirable. These include the following:

- Formal structure and control of training requiring a deliberate logic (tailoring learning to the individual based on rational decisions about performance).
- Precise control of task loading.
- Objective adjustment of the difficulty level of tasks.
- Structuring the link between the student's performance and the presented task.
- Emphasis on measurement during the training process.

- Requirement to analyze all the variables that can influence student performance and task difficulty.

- Record of the training process.

While these features are not peculiar to adaptive simulation, all are pertinent to the technique.

Assuming the efficacy of adaptive simulation, what training problems are adaptive techniques best suited to solve? This is a relevant question for design, since it appears that not all training will benefit from this approach. To date, it has been applied almost totally to tracking behavior and perceptual motor skills, so much so that it has become a major preoccupation of flight simulation. Some insights are provided below (see also McGrath and Harris 1971).

- Adaptive training methods are most probably called for in perceptual-motor tasks that are too difficult for a student to handle at the outset.

- Adaptive training is called for when the computer can substitute for the instructor and when the task is of such a high order of difficulty that it cannot be mastered unless it is broken down into component parts.

- Adaptive training methods seem warranted when training is already adaptive, but instructor controlled, and when it is desirable for reasons of cost, standardization, or (when it can be demonstrated) training effectiveness to mechanize the instructor's adaptive function. These methods are also appropriate when it can be shown that training time is significantly reduced or that a higher level of skill is reached in the same amount of time by replacing a fixed with an adaptive training schedule. The criterion should be cost-effectiveness, broadly interpreted and applied.

- Adaptive training systems are probably most useful in situations requiring considerable overlearning and high retention over time. They are most appropriate in systems where variables can be closely, perhaps infinitely, controlled; but application to part-task/whole-task grouped learning patterns may not be amenable to the close control over levels of difficulty that seems essential to the technique. The important problem is the relevance of the adaptive variable used as a forcing function (turbulence, for example) to the task for which the student is being trained.

- Automated adaptive training may be used for the purposes of reducing the need for human instructors, standardizing training procedures, making the decision function more objective and rational, or achieving greater precision of control in presenting tasks and instructional materials. These are important goals, but they can be met by other methods of automated, structured, or programed training that are not necessarily adaptive. The purposes that can be served uniquely by adaptive training must be those which are served by maintaining a continuously closed loop between the student's performance output and the task-stimuli input.

Thus, adaptive training methods are worthy of consideration when: 1) the task to be learned is of sufficient difficulty to require a significant amount of time to achieve mastery, 2) task improvement is a linear or progressive phenomenon, 3) the training situation lends itself to automated controls, 4) the subject population can be controlled to the extent necessary, and 5) the training task bears sufficient resemblance to the final behavioral model to have a reasonable transfer value.

Adaptive techniques automate an important instructor function, that of problem selection (that is, progressing through a graduated series of exercises to achieve the optimum training strategy). This involves the automation of two other functions: scoring of performance so that adaptation can occur; and providing information so that the student will know where to direct effort at reducing his error rate. In defining the information requirements for design, the following elements must be resolved.

1. Selecting the relevant adaptive variables (task modification to systematically change its difficulty).

2. Defining the performance measurement requirements (continuous/repetitive scoring of performance).

3. Specifying the adaptive logic (the function used to automatically adjust task difficulty based upon measured performance).

4. Determining the performance information to display.

3.4.10.2 Selecting Adaptive Variables. An initial decision is the choice of the parameter or variable which will be manipulated to adjust task difficulty. The task must be scalable along some dimension of graduated difficulty, either continuously or in step fashion. The adaptive variable selected must systematically affect the difficulty of the task.

A number of criteria for the selection of adaptive variables are summarized below to assist the human factors specialist in this important determination. The adaptive variable:

- must be clearly relevant to the operational task being trained; its variation should be along dimensions relevant to the skill being taught.
- must be capable of being described and quantified, i.e., it must be capable of being measured.
- must be related to task difficulty; changes in the adaptive variable must bring about changes in level of performance.
- must be capable of being varied in a systematic way; although this seems obvious, in a practical situation, it may not be easy to do.
- When used in devices for training for transfer to a different system, it should not inhibit or interfere with transfer of training.
- must be capable of being adjusted over a range commensurate with the student's skill both in increasing and decreasing difficulty. For example, the use of turbulence as an adaptive variable might be limited in its application because in some systems (e.g., the helicopter), the task difficulty for the beginning student must be reduced to some level below that of normal operation in calm air. That is, for the beginner, the task may need to be made easier than it actually is in the real system for most efficient training.
- must do no obvious violence to the training situation, i.e., it should be realistic in the sense that it varies in ways in which the real task varies so that it is acceptable to the student; the adaptive variable must not change the basic task so that it becomes strange and unreal to the student and not acceptable to him as a training situation.

3.4.10.3 Classes of Adaptive Variables. Various classes of adaptive variables are relevant to training system design. These are described next. The presentation tacitly assumes the rejoinder that the surety of selection awaits more empirical evidence. Within each of the classes of adaptive variable there is a variety of simulator features that can be varied, so that these singly or in combination provide a substantial range of possibilities. It is well to consider only a single continuum of difficulty for design. At present, the interactions among multiple dimensions are not well understood, hence complex scoring schemes are not encouraged without further research.

3.4.10.3.1 External Forcing Function--Turbulence has been most investigated as an adaptive variable in flight simulation, employed to make the control task more difficult. Obviously, its use at the outset of training is limited. Also, in systems difficult to control because of systems dynamics, difficulty level cannot be decreased below the level set by the system dynamics, hence, turbulence may not be a prime choice. In defining the turbulence spectrum, decisions involve variations in frequency, amplitude or both. Bandwidth of the forcing function appears critical in that it may interact with rate of change in difficulty and the length of the interval during which performance is measured. Wind velocity (head wind or tail wind) appears useful in that increases or decreases in ground speed influence difficulty level in terms of time constraints. Crosswinds have the effect of increasing the workload for the student in ground tracking since aircraft headings must consider this wind vector.

3.4.10.3.2 Vehicle Characteristics--Several types of difficulty factors have been identified as promising for manipulating task complexity. These include:

- control damping--increasing the moment of inertia on the control motions can be used to make the task less difficult. With damping, the student is not required to respond as quickly as without damping, hence loss of aircraft control, especially during initial training, will be less likely.

- center of gravity changes--CG shifting resulting from fuel loads may vary the student's workload in aircraft control.

- malfunctions--relevant system malfunctions are pertinent to graduated task difficulty levels.

3.4.10.3.3 Signal Characteristics--This includes degradation in signal characteristics (e.g., noise); the incidence of signals per unit of time in a mission context (e.g., density of ECM signals of varying priority classes for a given time unit), and simultaneity of signals at a given time (e.g., two or more high priority EW signals as immediate threats in the airborne environment).

3.4.10.3.4 Secondary Task Loading--The secondary task has been suggested as an adaptive variable, i.e., adjusting the primary task difficulty by secondary task loading. However, the use of secondary tasks must be considered carefully in training device design, if only from the viewpoint of task changing or realism. Of concern is the issue of whether secondary tasks change task difficulty or actually change the task. For flight training, the variables of communications and command pacing are perceived as realistic, but they may add to task structure more than just increasing the task difficulty. In other words, the object is not to just increase difficulty but also to make the task more realistic. If the secondary task is to be considered as an adaptive variable, then attention must be paid to, how the student perceives the two tasks, the relative difficulty level of the two tasks, the amount of student activity involved in performing both tasks and the manipulation rates for the secondary task. It seems best to argue that the secondary task technique is more useful as a laboratory research tool rather than as an adaptive variable for operational training.

3.4.10.3.5 System Quickening--In system quickening the actual output of the system is changed by the quickening. This is in distinction to display quickening wherein error scores are derived for displayed error rather than for system output. The investigations thus far, however, suggest that quickening and aiding are of relatively low priority as candidates for adaptive variables.

3.4.10.3.6 Effective Time Constant--Change in the effective time constant of the vehicle response (t_e), has been proposed as an adaptive variable. The effective time constant of the man-machine system is a measure of the time between control input initiation and the operator's detection of the vehicle response to the control input, i.e., the speed with which the operator detects the results of a control movement. It is a measure of the responsiveness of the vehicle to control movements and is made up of the speed of the vehicle response and the operator's threshold for detecting changes resulting from control inputs. Matheny and Norman(1968) showed t_e to be related to rate of learning and to final level of precision of control. Level of performance was related to the interactive effects of t_e and system gain, with the effects of gain most prominent during initial learning and t_e more important in determining final level of performance. For an adaptive training sequence, optimum gain and t_e would be provided in initial training. As training progressed, gain and t_e would be adjusted to achieve the task difficulty progression.

3.4.10.3.7 Changes in Control Order--Hudson (1964) suggested that changes in control order during training is an important issue; optimum learning may occur when the practice task involves moderate or average level of difficulty regardless of the level of difficulty of the criterion task. Level of training achieved is largely a function of level of difficulty during practice.

3.4.10.4 Measuring Performance. Obtaining relevant and reliable performance measures is as critical as is the selection of the adaptive variables for training, so much so that the success of adaptive training is predicated on adequate measurement. The research to date has focused on tracking tasks using traditional performance indices (absolute error, time-on-target) as performance criteria to adjust an adaptive variable affecting the task. Experience to date with adaptive measurement has been sparse and has centered primarily on flight simulation. For example, in the Synthetic Flight Training System, Device 2B24, measurement considers the important parameters in aircraft control and performance tolerances have been set based on best estimates guided by experience. The specified performance parameters and the suggested performance tolerances have already been shown in Table 13.

A research study (Kelley and Wargo 1968) recommends the following. Possible performance measurements for the training device should begin with basic vehicle control parameters--airspeed, altitude, and attitude during steady state flight. Error tolerances for each parameter must be established empirically for various flight conditions. Measurement should also consider task components such as vehicle status monitoring, navigation and communication even though these are more difficult to measure effectively. The scoring of flight path control during maneuvers can be achieved by computing repetitively the response of an "ideal" pilot which is compared to the student response on the basis of vehicle output parameters since there is a wide range of operator control manipulations that will result in the desired vehicle response. Instantaneous performance should be measured in terms of basic vehicle state parameters. The parameters suggested are: three coordinates of position; airspeed; heading; rate of climb/descent/ and pitch (roll and cross-track velocity could be used if found to be important). A nominal value should be computed for each scoring parameter via a computer-based model representing the desired vehicle state at each instant, and recomputed periodically based on new real-time parameters. Error tolerances about the minimal values for each scoring parameter should be established (e.g., four categories ranging from "within tolerance" to "far out-of-tolerance"). An accumulating error score should be kept for each scoring parameter. Scores not in tolerance should be weighted (incremental). Performance on all parameters together should be assessed by logical rules (adaptive logic) to determine if adjustments in task difficulty are warranted. (In determining the adaptive logic, tolerance limit settings and logic rules require examination of score distributions and intercorrelations on tasks performed by skilled pilots).

Another recent research concerned with measurement in the flight context (Vreuls and Obermayer 1971) recommends the measurement sets shown in Table 15 for the adaptive variables of turbulence and command pacing.

3.4.10.5 Adaptive Logic. A training system is adaptive to the extent that task difficulty level is an automatic function of measured performance (no instructor intervention). The adaptive change occurs as a result of the difference between a preset performance standard and the latest measurement of performance. Thus, the adaptive logic links the adaptive variables and performance measurements.

The error standard must be established. The student's actual moment-to-moment performance is compared against this criterion and task difficulty level is adjusted as a result of this comparison. Obviously, there is an optimum standard; less than this will degrade training efficiency. When the standard is too tight, the error tolerance is small and the adaptive system will automatically remain less difficult to the student; when the standard is too loose, the student will progress more rapidly to a more difficult task configuration.

The length of the performance sampling periods must be established. When the sampling period is too short, exaggerated changes in difficulty level may occur and task difficulty may exceed the student's momentary skill level. The design decision must consider the implications of slow varying vs. quick varying adaptive tasks, particularly, if large fluctuations in student performance are expected, since these may force the system to adjust difficulty level excessively. In this sense, slow varying adaptation represents a more reasonable selection than does quick-varying adaptation.

3.4.10.6 Display of Performance Information. Supplementary knowledge of results should be displayed, even though artificial and not directly related to the criterion task. Some digital readout of the momentary status of the adaptive variables seems sufficient. Device 2B24, for example, will employ a meter which gives the level of difficulty of the system at each moment. A two-part score is proposed. The first part (2-3 digits) identifies the mission or the problem installed; the second part (1-2 digits) identifies the level of problem difficulty as determined by the intensity of the adaptive variable.

Indicator lights may be used to depict out-of-tolerance conditions as they emerge. Augmented feedback may also be provided directly on a primary display, for example, in the form of an alphanumeric message alerting the student to a specific out-of-tolerance error.

TABLE 15. MEASUREMENT CANDIDATES FOR TURBULENCE AND PACING ADAPTIVE VARIABLES

MEASURE	FUNCTION OF	TOLERANCE
Altitude Error	Altitude Command	±100 Ft.
Altitude Rate Variability	Steady-State Climb/ Dive or Hold Command	±600 Ft./Minute
True Airspeed or IAS or Mach	Steady-State Airspeed Command	±20 knots or mach
Roll Average Error[1]	Bank Command	$\pm 5^{\circ}$
g-Error[1,2]	Bank Command	±.2 g for Pacing, ±.4 g for Turbulence
Turn Rate Error[1]	Bank Command	±.2 deg./sec. for Pacing

[1] These measures to be taken from the time a command is first achieved.

[2] g-error is the difference between the obtained value and the desired value.

(from Vreuls and Obermayer, 1971)

The issue of whether knowledge of performance information should be displayed continuously, periodically or event oriented, and directly or indirectly cannot be resolved at this time. It is, nevertheless, of importance to design.

Additional adaptive features of Device 2B24 are worth noting since this trainer is the first to include adaptive simulation in design. At present, four adaptive variables have been selected for implementation. These are:

- turbulence (either longitudinal axis or roll axis emphasis).
- control damping (increasing the moment of inertia on the control motions--i.e., airframe response)

- horizontal wind (headwind or tailwind to modify ground speed)

- crosswind

Error scoring for the purpose of adjusting task difficulty will be in percent time out-of-tolerance for each scored parameter. As it now stands, the scores will be treated separately for each parameter rather than being combined into a single score. To increase task difficulty, performance must be within tolerance for a designated percent of the sample time on all parameters being used in a training exercise. The entire task interval has been arbitrarily divided into 10-second intervals, i.e., every 10 seconds, time out-of-tolerance and error rate is examined on each parameter. In the initial programing, error rate may be set at 10 percent. Task difficulty will not change if performance is within tolerance 90% of the time during the sample period. If performance is acceptable less than 90% of the time, task difficulty will decrease; task difficulty will increase if acceptable performance exceeds these limits. The criterion function is reset to zero whenever the difficulty level changes. The magnitude of the adjustment in task difficulty will be a function of the particular adaptive variable being employed in each problem.

Each student will receive knowledge of results of progress via a two-part digital readout. The first part indicates the problem being practiced (this would indicate level of difficulty or stage of training if exercises are graduated in difficulty); the second part indicates the level of problem difficulty as determined by the intensity of the adaptive variable. Thus, a score of 18.50 indicates that problem 18 is in effect with a moderate intensity level for the adpative variable being employed (i.e., entry difficulty level of 3; exit criterion difficulty level of 9).

It is emphasized that the above describes initial programing requirements since the device is not expected to be on-line prior to 1971. Thus, adjustments will be made and concepts may be revised through a series of successive approximations until the optimum values are achieved as research information and experience with the on-line device accumulates.

The problems besetting Device 2B24 in implementing adaptive sequencing have been considered at an adaptive training workshop at the University of Illinois (McGrath and Harris 1971). Excerpts from this deliberation are described below.

- The major problem is in the performance measures. The validity and the reliability of the proposed measures can be questioned. Research is recommended on the performance measurement problem before very much reliance is placed on the adaptive training feature of the system. For example, percent of time out-of-tolerance may be a useful measure for some of the training but its usefulness is a function of the validity of the tolerances employed.

- The 10-second interval of performance measurement for determining adaptive changes will probably be too short. The available empirical evidence on adaptive training seems to favor the "slowly adapting" system, and so does theory. Moreover, on the grounds of psychophysics alone, there are few aspects of human performance that can be measured reliably in 10 seconds; and if the performance measurement is unreliable, then, of course, the adaptive "logic" is reduced to a largely random process.

- The time out-of-tolerance measures of performance may have to be better defined. It is possible that much information of potential value may be lost during the "in-tolerance" performance.

- The planned approach that calls for the student to practice control on one axis, then on two axes, and so on, will lead to difficulties in transfering from one task to another in the sequence. The freezing of any axis or set of axes may cause the student to adapt to response modes that are incompatible with response modes required when the axis or axes are unfrozen. This situation could result in significant negative, or at least neutral, transfer from one task to the next.

- A good start has been made on the choice of adaptive variables. Of course, the adaptive logic requires empirical study with a great deal of attention given to the standards employed. The overriding problem, however, is that of performance measurement. There is doubt that the measurement approach presently planned is reliable, or that it will result in effective adaptive task control.

- A great deal of refinement is going to have to take place in the exit criteria and in the way a student is tracked through his training. It is anticipated that the 1 to 9 scheme for scaling difficulty will have to be revised and that a system for accumulating milestone "misses" will have to be incorporated. Also, student motivation will probably not be handled very well by the current scheme.

3.4.11 AUTOMATED VERBAL MESSAGES

In training systems possessing an automated monitoring, evaluation and scoring capability, there are instructional sequences that benefit from the use of prerecorded verbal messages. With automated training evaluation, these messages make available coaching information (cues and prompts which provide supplementary information about performance before or during student response) and error alerting information (augmented feedback which provides performance information immediately as accrued, i.e., information feedback during or immediately after student performance). They serve also to relieve the instructor from time consuming performance monitoring and communications activities, the burden of which is significant in multi-student trainers wherein each student performs independently.

At present, this instructional technique is most appropriate to the task requirements in flight simulation. Voice messages are transmitted to the cockpit from a computer-driven recorded voice system. Individual messages are assembled word by word and formatted into messages under computer direction as a consequence of student control or vehicle actions. These precise information messages are most appropriate in 1) task situations where communications requirements are heavy, e.g., the coaching requirements in a Ground Controlled Approach (GCA); and 2) situations where the messages are clearly correlated with emergencies or developing out-of-tolerance system states, e.g., performance alerts which announce that a measured parameter soon will, or currently exceeds a preset error tolerance.

The requirements for the design of a computer controlled voice system include the following categories of information.

- selection of the instructional situations employing automated verbal messages, e.g., performance alerts (out-of-tolerance), emergency procedures, task segments.

- precise definition of the task structure benefitting from the automated voice generating technique.

- definition of the word universe appropriate to the communication requirements of the task situation. An example is provided in Table 16 of a word vocabulary currently utilized by NTDC.

- definition of the number of messages required and the structure of each message.

TABLE 16. NTDC WORD LIST

ABOVE	21	EXECUTE	2B	MINUTE	35	SILENCE	0A
ACKNOWLEDGE	61	FAST	1F	MISSED	75	(SILENCE)	00
AFTER	A1	FEET	6B	NAUTICAL	B5	(SILENCE)	40
AGAIN	13	FINAL	AB	NAVY	36	(SILENCE)	80
ALPHA	4A	FIVE	07	NINE	48	SIX	47
ALSO	22	FOR	2C	NINER	88	SLIGHTLY	3E
ALTITUDE	62	FORWARD	56	NO	76	SLOW	9E
AND	A2	FOUR	86	NORMAL	B6	SOUTH	1B
ANSWER	53	FOXTROT	0C	NORTH	98	SPEED	5B
APPROACH	23	FROM	6C	NOSE	19	START	9B
APPROACHING	63	FURTHER	AC	NOT	37	STICK	1C
ARE	93	GLIDE	2D	NOVEMBER	8E	SURFACE	7E
AT	A3	GOLF	4C	OBSERVER	77	TAKE	BE
AVAILABLE	24	GOOD	6D	OF	B7	TANGO	90
BACK	14	GUSTY	AD	OFF	59	THAT'S	5C
BE	96	HALF	49	ON	38	THE	3F
BEEN	64	HEADING	2E	ONE	85	THESE	9C
BEGIN	A4	HEAR	6E	OR	78	THIS	7F
BELOW	25	HELLO	17	OSCAR	0F	THOUSAND	BF
BRAVO	8A	HOTEL	8C	OVER	B8	THREE	46
CANCELLED	65	HOW	AE	PAPA	4F	THRESHOLD	20
CHARLIE	0B	HUNDRED	2F	PATH	39	TO	60
CLEAR	A5	IF	6F	PATTERN	79	TOUCHDOWN	A0
CLEARENCE	66	IMMEDIATELY	57	PEDDLE	99	TOWER	01
CLEARED	26	IN	AF	PER	B9	TRANSMISSION	41
CLIMB	A6	INCREASE	97	PERFORM	3A	TURN	81
COMPLETE	27	INDIA	0D	PLEASE	9F	TWO	06
CONFIRMED	67	INFORMATION	30	PLUS	1A	UNABLE	02
CONTACT	A7	IS	70	POINT	7A	UNIFORM	11
CONROL	5E	JULIET	4D	PRECISION	BA	UP	1D
CONTROLLER	28	KILO	8D	PRESENT	5A	VICTOR	51
CORRECT	54	KNOTS	B0	QUARTER	09	VISIBILITY	42
CORRECTED	68	LAND	31	QUARTERS	89	VISUAL	82
CORRECTION	A8	LANDING	71	QUEBEC	8F	VISUALLY	03
COURSE	29	LEFT	B1	RATE	3B	WELL	43
DAY	69	LEFT OF	32	RECEIVED	7B	WEST	5D
DECREASE	94	LEVEL	18	RECOMMEND	5F	WHEELS	83
DEGREES	A9	LIGHTS	72	RIGHT	BB	WHISKEY	91
DELTA	4B	LIMA	0E	RIGHT OF	3C	WIND	04
DESCEND	15	LOUD	B2	ROGER	7C	WING	9D
DESCENT	2A	MAINTAIN	33	ROMEO	10	WITH	1E
DIVE	55	ME	73	RUNWAY	BC	WITHIN	44
DO	6A	MIKE	4E	SECONDS	3D	XRAY	12
DOWN	AA	MILE	B3	SETTINGS	9A	YANKEE	52
EASE	95	MILES	34	SEVEN	87	YOU	84
EAST	16	MINIMA	74	SHOULD	7D	YOUR	05
ECHO	8B	MINIMUM	B4	SIERRA	50	ZERO	45
EIGHT	08	MINUS	58	SIGHT	BD	ZULU	92

- assignment of message priorities when two or more messages are appropriate simultaneously, e.g., when two parameters are out-of-tolerance at any given time.

- selection of the timing sequence for successive messages for the same system state, e.g., realerting the student at given intervals for a parameter that continues to be out-of-tolerance. Included here is the decision on automatic (computer) halt of the exercise with continued student violation of an error envelop.

- means for modifying the verbal messages and for overriding a message during an exercise or portion thereof.

Two examples of currently employed voice generation systems are provided below. The first is a system which was incorporated in a research study which attempted to demonstrate the technical feasibility of automating portions of a weapon system trainer (Charles and Johnson 1971). A ground Controlled Approach (GCA) and emergency procedures tasks (F-4 aircraft characteristics) were selected for automated implementation on the NTDC Training Device Computer System (TRADEC system) and tested with operational pilots. The computer-controlled voice system employed the vocabulary list shown in Table 16; messages for the GCA and emergency procedure exercises were assembled by the Meta-Symbol procedure in this program. The following messages were employed in the automated programs.

CLIMB AND MAINTAIN 2500 FEET, HEADING 045 DEGREES

CLEARED RUNWAY 04

CORRECT HEADING IS ____

HEADING IS GOOD

TURN LEFT HEADING _____

TURN RIGHT HEADING _____

NAVY 123, CONTACT 9 MILES FROM TOUCHDOWN, FINAL CONTROLLER

NAVY 123, IF ON FINAL AND NO TRANSMISSION IS RECEIVED FOR 5 SECONDS TAKE OVER VISUALLY; IF UNABLE EXECUTE MISSED APPROACH

NAVY 123, PRECISION MINIMA 200 FEET, 1/2 MILE; IF RUNWAY NOT IN SIGHT AT MINIMA, COMPLETE APPROACH TO TOUCHDOWN IF THE TRANSMISSION TO EXECUTE MISSED APPROACH IS NOT RECEIVED

NAVY 123, ON FINAL, DO NOT ACKNOWLEDGE FURTHER TRANSMISSION; APPROACHING GLIDE PATH, BEGIN CORRECT RATE OF DESCENT

COMPLETE LANDING SETTINGS

5 MILES FROM TOUCHDOWN

3 MILES FROM TOUCHDOWN

2 1/2 MILES FROM TOUCHDOWN

2 MILES FROM TOUCHDOWN

1 1/2 MILES FROM TOUCHDOWN

1 MILE FROM TOUCHDOWN

3/4 MILE FROM TOUCHDOWN

1/2 MILE FROM TOUCHDOWN

OVER LANDING THRESHOLD

OVER TOUCHDOWN

CLEARED FOR TAKE OFF

COMPLETE TAKE OFF SETTINGS

COMPLETE DESCENT; CLEARED TO LAND

ABOVE GLIDE PATH

BELOW GLIDE PATH

ON GLIDE PATH

SLIGHTLY ABOVE GLIDE PATH

SLIGHTLY BELOW GLIDE PATH

WELL ABOVE GLIDE PATH

WELL BELOW GLIDE PATH

WIND _____, _____ KNOTS

EXECUTE MISSED APPROACH

The second example is provided by the Synthetic Flight Training System, Device 2B24. Automatic audio message alerts are given to a student whenever an engine or flight parameter exceeds preset error tolerances. The alert consists of a statement of the parameter which is out-of-tolerance. When more than two parameters are out-of-tolerance simultaneously, the alerts are limited to the two highest priority parameters. Parameter deviations which continue, are realerted at 10 second intervals. In addition, five short coaching messages (10 seconds duration) are provided, designed to relieve the instructor of the requirement for continuous verbal instructions. The instructor is enabled to override messages as appropriate to the instructional strategy.

3.4.12 COMMUNICATIONS

The communications capability at the instructor console involves intra-trainer communications and the simulation of radio communications.

3.4.12.1 Intercommunications. The following information requirements must be considered in design (as appropriate).

- Extent of representation--replica of the operational system counterparts; the use of actual system communications components (e.g., controls and control panels, headsets, microphones, etc.) configured and operated as in the operational system.
- Instructor-student communications--selective communication with individual students, any combination of students, all students, regardless of student control settings.
- Status displays depicting which students are transmitting, receiving and what transmitters are being used; call light indication of which student is requesting assistance.
- Instructor monitoring of all communications channels.
- Student-to-student communications.
- Instructor to remote instructor(s)/operator communications unavailable to students.
- Remote instructor to student links.
- Common audio network--to place any combination of trainee stations in a common network, so that with proper tuning/switching, each student may hear all student transmissions or instructor transmissions.
- Static, background noises, background and simultaneous communications from other sources.
- Extra-vehicle communications (e.g., messages from other units, ground control, etc.).

3.4.12.2 Radio Communications. In flight simulators a capability is required for instructor monitoring and controlling of radio communications and for performing certain ground-to-air control functions (e.g., GCA, air traffic control, etc.). For example, upon hearing a student's call to a station, the instructor is able to determine the equipment being used and the station being called. Then, via proper switch activation, he serves as ground communicator. As a case in point, when a student calls and the UHF, in-range and in-tune light, is on, the instructor can determine which station is tuned in (e.g., by operating the ARC-51 UHF switch and reading the frequency of the station). This enables him, via the use of a facilities chart, to determine that station for which he will act as ground communicator.

3.4.12.3 Communications Controls. The following control capabilities should be accounted for:

- speaker/headset selector and volume controls,
- alternate action controls to select the receiver over which a student will hear the instructor's voice (e.g., FM, VHF, NAV, UHF),
- controls and indications for selecting and switching all student combinations,
- controls to activate prerecorded verbal messages (e.g., ground control messages, air traffic control clearances, etc.),
- controls for recording the time of occurrence of errors in student communications (i.e., errors in terminology or procedures temporally inadequate),
- controls for recording audio transmissions of the student; these controls include: record and playback, indexing and fast speed forward/rewind (see Chapter 3.4.13),
- controls for selected surface radio/navigation facilities,
- controls for channel and frequency selection and in-range conditions data between the selected operating equipment and the surface facility,
- layout of communications controls--this involves the layout and switching of controls (multi-trainee stations), inter-student links, status display of students on the air, volume control, "hot mike" capability, etc.

3.4.13 POST-EXERCISE INSTRUCTIONAL CAPABILITY

The capability for post-exercise instructional control is a crucial design consideration. It is tied-in directly with the evaluation and the control of student performance. Based on the measurement system design for the trainer, two instructional functions are served: assessing the progress and outcomes of instruction (performance evaluation); and providing information to the student on how the results of his performance conform to expectations or norms (knowledge of results).

The post-exercise instructional capability centers on the critique, or debriefing, function. The design issues concern the printout of student performance indications, hardware for providing mission critique in the trainee station, and special equipments employed in formal critique sessions which are used to reconstruct an exercise just completed. Two major classes of information requirements must be considered in providing the requisite performance evaluation and knowledge of results capability. These relate specifically to the design requirements for 1) hard copy records of performance, and 2) graphic assists for formal debriefing sessions.

3.4.13.1 Hard Copy Records. Retrievable permanent records of all significant error scoring and time and event happenings should be available on demand throughout an exercise. The permanent record serves two purposes: the immediate debriefing requirements (for instructional control) and the longer term school record keeping (for quality control). Since the computer is capable of recording all time and event happenings, and all deviations from preset tolerance levels that occur in an exercise, the significant factors that relate to student performance can be provided via hard copy printouts. For example, time histories of performance are easily obtained, as is status or event information. Frequency data are easily assembled and manual control scores (e.g., integrated error rates) can be computed swiftly. Larger segments of performance and terminal (system) outputs are also achievable directly. The computer is similarly able to combine, integrate and weight scores and compare the results against defined error tolerance criteria.

Software programing and hardware design must consider the following information requirements.

a. types of records--Various types of hard copy records are available for exercise critique and for school record-keeping purposes.

- time and event printout--This provides a record of all significant actions taken and the times of accomplishment throughout the exercise.

- error printout--This provides a record of performance errors throughout the exercise. Error indications may be in terms of types or groupings, or of all parameters which exceed programed tolerances and may include a computation of the amount by which each parameter is exceeded as a function of time from exercise start.

- hard copy graphs--This provides a graphic representation of performance evaluation for use in off-line analysis for quality control. In Device 2B24, for example, the program output data for checkride evaluation, provides frequency and cumulative time of error by groups of students (e.g., by instructor or by class) for each maneuver, for all pertinent parameters without respect to the maneuver and for each parameter separately by maneuver. Each graph contains separate plots of the same data for at least one comparison group or a reference standard group. Also provided is an indication of the statistical significance between groups compared.

- error summaries--This provides short summaries of error deviations made during an exercise. The summaries may depict errors per class, errors achieved per mission segment, total error score per exercise, etc. A single page summary of performance is useful in the post-exercise critique. A performance summary per exercise may also be filed for each student; this provides an assist in diagnosing performance error and in determining subsequent training emphasis.

b. information to record--An important feature for design is what and how much information to record and in what form. The possibilities are many, ranging from alphanumeric to graphic information. The major concern is for alphanumeric data. Various options are indicated below:

- printout of all significant events accomplished and their time of initiation and completion.

- printout of performance on selected parameters--For aircraft simulation, it is desirable to record performance in the key aircraft and engine parameters, for example:

  - aircraft attitude/position geometry (heading; altitude; airspeed; pitch angle; roll angle; flight path and approach slope).

    - force/rate (turn rate; stick rates; rudder, roll, pitch and yaw rates; G loading; and vertical velocity).

    - position of aircraft controls--(stick; rudder and throttle positions)

    - discrete events (flaps; landing gear; speed brakes; elevator tabs).

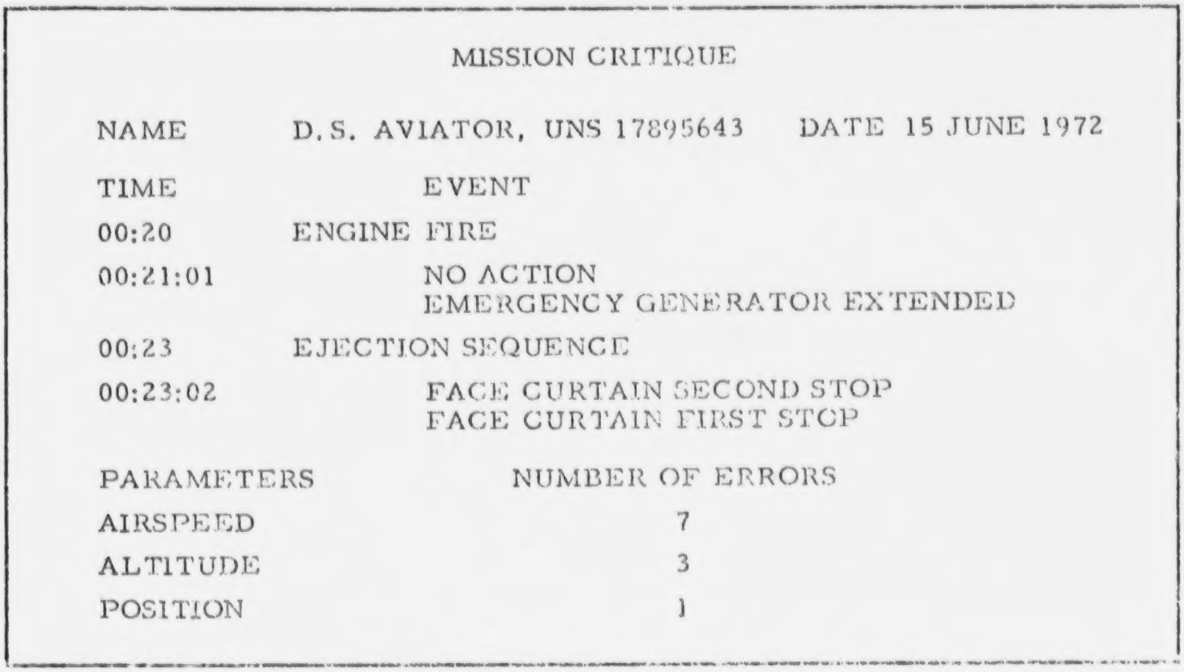
    - instrument readings.

    A desirable capability is the simultaneous recording of a given number of the pertinent parameters from the total list, on a continuous basis (selectable on demand).

- printout of deviations from all preprogramed performance parameters as the tolerance envelope is exceeded--an example is provided by Device 2F100 (A-7E Aircraft) which records the deviation of all selected parameters which exceed the preprogramed error tolerances. A teletypewriter prints the following information: the parameter exceeded, the aircraft position, elapsed time, and the direction of deviation. The record is available when the parameter returns to within the allowable tolerance.

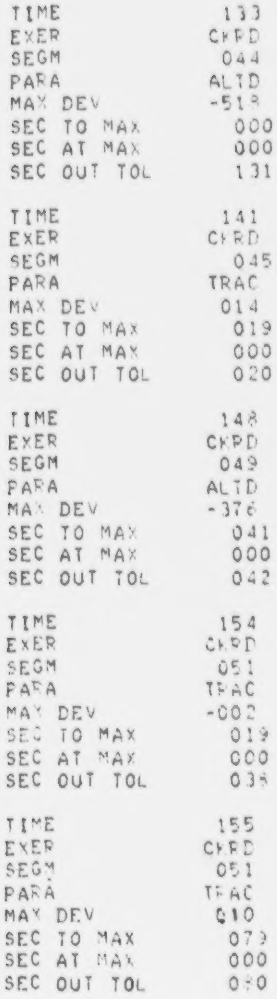
- printout of all errors committed--for certain training situations it is desirable to record all classes of error committed, e.g., by type and frequency or by deviations or omissions from a procedural sequence.

c. formatting of retrievable records--A major design issue is the formatting requirements in the printouts. The information, which is tailored to the type of hard copy record desired, involves: the specific information classes to provide, the form of the information presented (e.g., alphanumeric or graphic), and the layout and organization of the selected record. Some examples of hard copy formats are shown below to indicate the range and extent of the information requirements for design. Figure 31 presents a summary mission critique printout proposed by Goodyear Aerospace Corporation for Device 2-F100 (1971). The printout presents a summary of error excesses, that is, when the instructor-established tolerances for the selected parameters are exceeded. In addition to the identifying student and mission information, the following is provided. For each procedure, the first line indicates what the student did; the second line indicates what should have been done. All parameters exceeded and frequency of occurrence are indicated. From the example in Figure 31, an engine fire occurred at 20:00 after Comex. The emergency generator should have been extended at 21:01, but the student took no action. At 23:00, an ejection was begun. The student pulled the face curtain to the second stop when he should have used the first. Throughout the mission, airspeed tolerances were exceeded 7 times, altitude 3 times, and position once. This format gives both the instructor and the student a written summary of the errors committed during the exercise. Figure 32 provides a sample of an actual printout of student performance in Device 2B24. It is part of a summary of errors made by a pilot in an automatic checkride mission. The printout occurs whenever the student exceeds the tolerable error envelop for a given parameter. Each information block pertains to a parameter in which performance has deviated from the acceptable error envelop. The record is self-explanatory providing: time of error occurrence in the mission; designated exercise (e.g., checkride); segment of the mission in which the error occurred; the parameter involved (e.g., altitude); the maximum deviation of the error (e.g., -518 refers to feet below the desired altitude); time (seconds) to achieve the maximum error and time (seconds) at maximum error; and total time (seconds) out-of-tolerance.



```
                        MISSION CRITIQUE

  NAME       D.S. AVIATOR, UNS 17895643    DATE 15 JUNE 1972

  TIME                 EVENT

  00:20      ENGINE FIRE

  00:21:01             NO ACTION
                       EMERGENCY GENERATOR EXTENDED

  00:23      EJECTION SEQUENCE

  00:23:02             FACE CURTAIN SECOND STOP
                       FACE CURTAIN FIRST STOP

  PARAMETERS                NUMBER OF ERRORS

  AIRSPEED                         7

  ALTITUDE                         3

  POSITION                         1
```

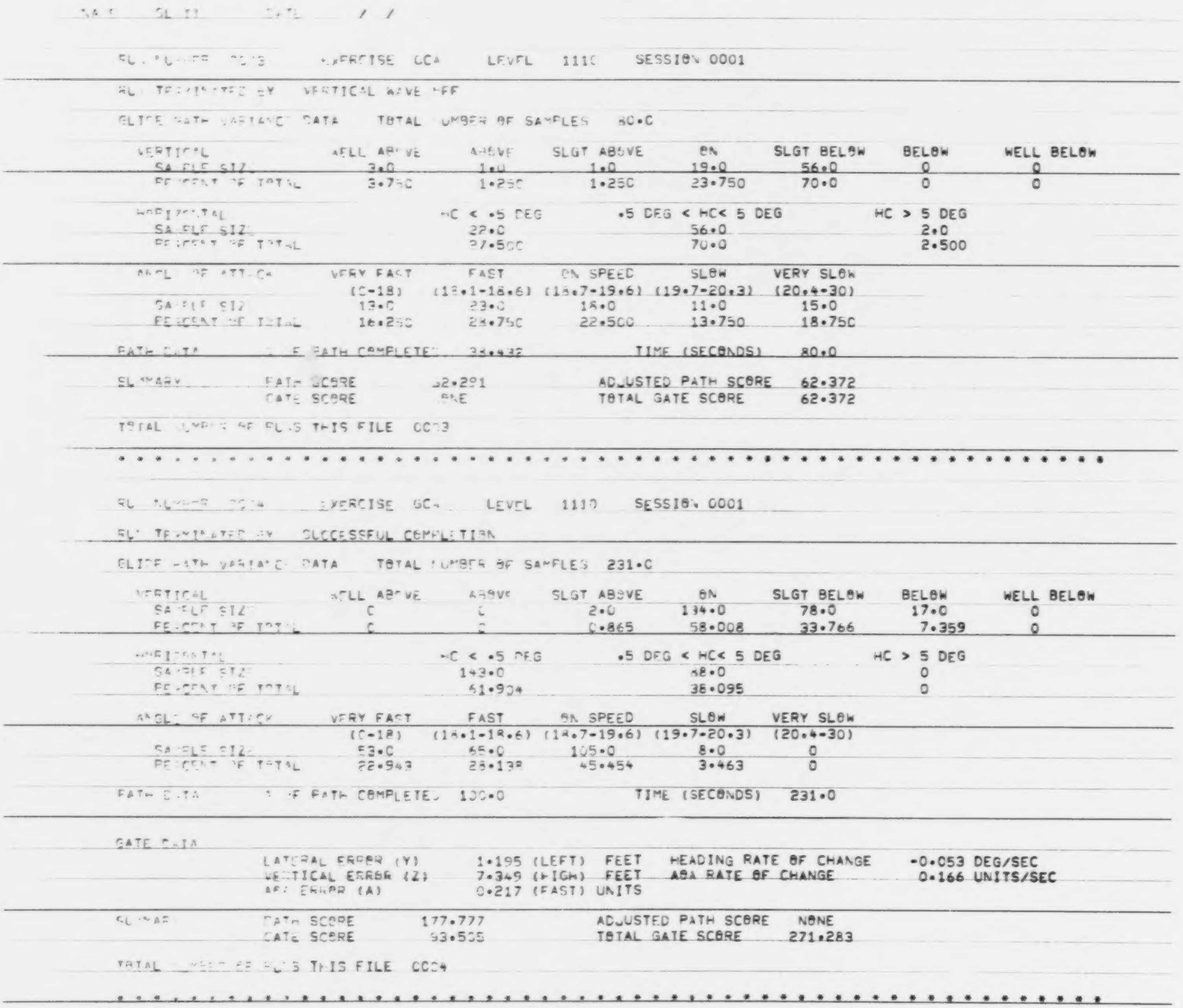
Figure 31. Summary Printout for Critique.



```
TIME              133
EXER             CKPD
SEGM              044
PARA             ALTD
MAX DEV          -518
SEC TO MAX        000
SEC AT MAX        000
SEC OUT TOL       131

TIME              141
EXER             CKRD
SEGM              045
PARA             TRAC
MAX DEV           014
SEC TO MAX        019
SEC AT MAX        000
SEC OUT TOL       020

TIME              148
EXER             CKPD
SEGM              049
PARA             ALTD
MAX DEV          -376
SEC TO MAX        041
SEC AT MAX        000
SEC OUT TOL       042

TIME              154
EXER             CKPD
SEGM              051
PARA             TRAC
MAX DEV          -002
SEC TO MAX        019
SEC AT MAX        000
SEC OUT TOL       038

TIME              155
EXER             CKPD
SEGM              051
PARA             TRAC
MAX DEV           010
SEC TO MAX        079
SEC AT MAX        000
SEC OUT TOL       080
```

Figure 32. Sample printout of student performance (error deviation per parameter), Device 2B24.

Figure 33 presents a sample printout of pilot performance on the NTDC research simulator (TRADEC). The recorded segment summarizes performance on an automated ground controlled approach (GCA). Figure 34 provides a hard copy format that appears useful for performance critique in the Air Navigation Trainer, Device 1D23 (Bark, et al 1969). The time and event printout is produced for each trainee station in the device.



```
NAME    SL II        DATE     / /

RUN NUMBER 0003       EXERCISE  GCA     LEVEL   1110     SESSION 0001

RUN TERMINATED BY   VERTICAL WAVE OFF

GLIDE PATH VARIANCE DATA    TOTAL NUMBER OF SAMPLES   80.0

  VERTICAL                WELL ABOVE     ABOVE    SLGT ABOVE      ON      SLGT BELOW     BELOW       WELL BELOW
    SAMPLE SIZE               3.0         1.0        1.0         19.0       56.0           0            0
    PERCENT OF TOTAL          3.750       1.250      1.250       23.750     70.0           0            0

  HORIZONTAL                          HC < .5 DEG        .5 DEG < HC< 5 DEG            HC > 5 DEG
    SAMPLE SIZE                          22.0                   56.0                     2.0
    PERCENT OF TOTAL                     27.500                 70.0                     2.500

  ANGLE OF ATTACK         VERY FAST      FAST       ON SPEED      SLOW      VERY SLOW
                           (0-18)    (18.1-18.6) (18.7-19.6) (19.7-20.3) (20.4-30)
    SAMPLE SIZE             13.0         23.0        18.0         11.0       15.0
    PERCENT OF TOTAL        16.250       28.750      22.500       13.750     18.750

PATH DATA         % OF PATH COMPLETED   33.432            TIME (SECONDS)    80.0

SUMMARY           PATH SCORE          32.291            ADJUSTED PATH SCORE   62.372
                  GATE SCORE          NONE              TOTAL GATE SCORE      62.372

TOTAL NUMBER OF RUNS THIS FILE  0003

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

RUN NUMBER 0004       EXERCISE  GCA     LEVEL   1110     SESSION 0001

RUN TERMINATED BY   SUCCESSFUL COMPLETION

GLIDE PATH VARIANCE DATA    TOTAL NUMBER OF SAMPLES  231.0

  VERTICAL                WELL ABOVE     ABOVE    SLGT ABOVE      ON      SLGT BELOW     BELOW       WELL BELOW
    SAMPLE SIZE               0           0          2.0         134.0      78.0          17.0          0
    PERCENT OF TOTAL          0           0          0.865       58.008     33.766         7.359        0

  HORIZONTAL                          HC < .5 DEG        .5 DEG < HC< 5 DEG            HC > 5 DEG
    SAMPLE SIZE                         143.0                   88.0                     0
    PERCENT OF TOTAL                     61.904                 38.095                   0

  ANGLE OF ATTACK         VERY FAST      FAST       ON SPEED      SLOW      VERY SLOW
                           (0-18)    (18.1-18.6) (18.7-19.6) (19.7-20.3) (20.4-30)
    SAMPLE SIZE             53.0         65.0        105.0        8.0        0
    PERCENT OF TOTAL        22.943       28.138      45.454       3.463      0

PATH DATA         % OF PATH COMPLETED  100.0            TIME (SECONDS)   231.0

GATE DATA
                  LATERAL ERROR (Y)       1.195 (LEFT)  FEET    HEADING RATE OF CHANGE     -0.053 DEG/SEC
                  VERTICAL ERROR (Z)      7.349 (HIGH)  FEET    AOA RATE OF CHANGE          0.166 UNITS/SEC
                  AOA ERROR (A)           0.217 (FAST) UNITS

SUMMARY           PATH SCORE         177.777            ADJUSTED PATH SCORE   NONE
                  GATE SCORE          93.505            TOTAL GATE SCORE     271.283

TOTAL NUMBER OF RUNS THIS FILE  0004

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

Figure 33. Hard Copy Printout of Pilot Performance In An Automated GCA Exercise On The NTDC Research Simulator (TRADEC).

Trainee Station ____________________ Page ________

Time: ____________ Event: Heading Change

Lat. ________ Long. ________
WD. ________ WS ________
HD ________ GT ________
GS ________ TAS ________

AID:

TACAN	TACAN	VOR
118.4	120.3	117.1

Diagnostics:
Nav Aids Out of Range:
120.3
Out-of-Tol.

Time: ____________ Event: 10-min. Fix

Lat. ________ Long. ________
WD ________ WS ________
HD ________ GT ________
GS ________ TAS ________

AID:

TACAN	TACAN	VOR
118.4	120.3	113.1

Time: ____________ Event: Annunciator Input

Lat. ________ Long. ________
WD ________ WS ________
HD ________ GT ________
GS ________ TAS ________

AID:

VOR	TACAN	VOR
113.1	120.3	117.1

Diagnostics:
ETA Correct

Figure 34. Time and event format anticipated for the Air Navigation Trainer. (from Bark, et al 1969)

In addition to alphanumeric printouts, graphic records provide data for performance critique and for off-line analysis (school record keeping). A representative example is the graphic recording utilized in Device 2F90 (TA-4J aircraft). An eight-channel recorder provides a continuous record of the extent of error deviations for selected parameters relevant to the specific flight segment being performed.

d. hard copy selection--A capability is required for initiating and terminating hard copy records of performance, on demand. The instructor must be provided the means for 1) selecting any of the programed performance variables (parameters, events, system states); 2) selecting the sampling rate; and 3) selecting the medium for recording (e.g., CRT, line printer, magnetic tape, typewriter, digital plotter). Controls must also be provided for selecting any of a number of programed hard copy formats at any time during an exercise and upon completion of a programed exercise.

e. printout speed--The issue of speed of the hard copy printout must be carefully considered. Time and event, error deviation and error summary records required for exercise debriefing must be available within moments after exercise completion. Similarly, specific performance data required during the exercise must be available, as accrued. No stringent time constraints are placed on the output of more detailed records for school record keeping and for evaluation exercises (e.g., standardized checkride missions).

f. data storage--Lengthy training exercises in multi-student contexts (e.g., several hours duration) require a consideration of hard copy formats in terms of data storage. The size and number of blocks of data must be considered for defined time periods. For example, in Device 1D23, Air Navigation Trainer (NTDC 1971) it is reasonable to assume that an average of one data block per five minutes of mission type will be stored and printed for each student. Thus, thirty-six blocks of data would be required for each of 40 students for a three-hour exercise. The printout requirements for this sizeable amount of data must be correlated with output rates of available printing means.

3.4.13.2 Video Recording and Playback. A record and playback system (closed circuit TV used in conjunction with video recording and playback equipment) provides the capability for the student to view his own performance (instant playback, if desired) and compare it against some objective reference. The instructional purposes served include demonstrations of desired performance and the critique of performance completed (knowledge of results).

The information requirements for design include the following:

- the content (tasks, maneuvers) of performance most suited to replay within the finite capacity of the recorder.
- means for control of the starting point for, and the exiting from the playback mode.
- definition of playback mode time (real, slow times).
- means for freeze, restart, terminate or bypass portions of the playback.
- definition of standards or expected outcomes for comparison with student performance (knowledge of results derived from comparing performance with idealized maneuvers or segments, or standard procedures).

3.4.13.3 Pictorial Representation. Certain classes of training devices, particularly complex team trainers do not possess many automated instructional features in design. Characteristically, automated preprogramed mission scenarios are not employed and only a rudimentary measurement system is installed. Most often, hard copy printouts of team performance are not available. These team training contexts (tactical decision-making, operational procedures training) rely heavily on the manual structuring and control of the instructional environment, and the post-mission critique is based on the observations and judgments of subject matter experts.

In these situations, special equipments are required to support the critique function. Usually, this is in the form of a pictorial reconstruction of a just completed exercise. This mission replay, presented to the assembled team in a central briefing/critique area, involves some form of visual display projection with or without a correlated audio recording of communications. An example is the mission reconstruction utilized in Device 14A2, ASROC/ASW Early Attack Weapon System Trainer (NTDC 1964). A visual display projection of the total mission geometry and critical events is provided in support of the mission debriefing.

The information requirements for a situational display of this type for mission reconstruction include the following:

- plot characteristics (scale, mission area, relative geometry of the engagement)
- vehicle symbology (own ship, submarine(s) assist ship(s), aircraft)

- event symbology (e.g., markers for torpedo firing, weaponry)
- track depiction and coding (line traces for specific tracks, color coded; weapon traces)
- speed control of the reconstruction (real time, fast time, selective advance or indexing capability)
- capability for instructor insertion of events into the display (e.g., marker symbols)
- performance information of error indications (e.g., hit or miss, water entry point)

The most current pictorial displays for debriefing are computer generated. For example, Device 2B24, Synthetic Flight Training System, employs graphic plots to display ground track history for each aircraft. The recalled ground tracks are presented for full scale or for any of six controlled approach sectors. All ground tracks are shown in their true geographic locations on map backgrounds (i.e., the pertinent geographic area is represented at the center of the display with the ground tracks positioned appropriately). A zoom mode is also provided to examine portions of the ground track in detail. In this mode, a given aircraft is positioned in the center of the display area, with the track and map background of the selected scale appropriately arranged about it.

3.4.13.4 Audio Recording. Multichannel voice recording and playback (student(s) and instructor channels) provides a continuous record of voice transmission throughout an exercise. In the recording mode, the voice transmissions are recordable automatically whenever a transmitter is activated during an exercise, with replay controlled from the instructor station. The information requirements for design include the following:

- number of discrete record and playback channels on the same tape.
- number of recorders and the organization of recording channels required (for training devices comprising multiple independent trainee stations).

- indexing capability of voice recording by time or events, in order to permit communications playback in real time, or condensed time (omission of blank portions of the tape), or selectively for any portion of the tape track involving a recorded performance event.
- minimum continuous recording time for each tape.
- adequate forward and rewind search capability in replay mode.

3.4.14 HUMAN ENGINEERING DESIGN

It is tacitly assumed that the basic human engineering design standards and military specifications are applicable throughout the device design process. Further, it is reasonable to expect that human engineering should not be considered as a separate design feature but as an associate design requirement integral to the development of the trainer as an instructional tool.

A discussion of human engineering requirements is not provided here since the design area is substantial in its own right possessing a well developed body of literature with established principles and practices. A number of military standards and specifications are current which specify the human engineering criteria, data and requirements for the design of the training device and its component parts. Principles and guidelines appropriate to trainer design are articulated in the following documents and these should be utilized, as appropriate, in technical approach determination.

MIL STD 1472A	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL T - 23991C	Training Devices, Military; General Specification For
MIL T 82335	Trainers, Flight; General Specification For
MIL T 9212B	Trainer, Flight Simulator, Aircraft, General Requirements For
MIL H 46855	Human Engineering Requirements for Military Systems, Equipment and Facilities
MIL I 82356	Instruments Simulated, For Aircraft Training Devices; General Specification For

The specifics of human engineering design are grouped under the following classes of information. Details relevant to each may be found in the above referenced standard documents.

a. Human engineering criteria and data apply to the design of the workplace and the man-equipment interfaces as dictated by the instructional functions to be performed. Layout and configuration are governed by the anthropometry, workspace, maintenance and safety requirements specified in the appropriate standard.

b. Layout should be accomplished in modularized components consistent with primary and secondary use requirements and good design practices. Console configurations should reflect the groupings of displays and controls to accommodate related functions and positioned in terms of frequency of use and criticality. Console design must also consider flexibility in usage (e.g., accommodating a single instructor or simultaneous use by more than one instructor).

c. Constraints in the workspace and in the equipment layout require special consideration, for example,

- space limitations in room size.
- integration of components (e.g., layout which does not compromise visibility in a central briefing room; placement of components to afford direct visual access to all trainee stations).

d. Lighting--Illumination criteria are provided in MIL-STD-1472A. All panels, recorders, instruments, controls and work surfaces are illuminated as specified. Where different illumination criteria are applicable to an area, the highest recommended illumination level pertains.

e. Acoustical noise--Facility and equipment noise generation and penetration should be controlled in accordance with the requirements of MIL-STD 1472A.

f. Panel markings and displays and controls--The following features must be considered in design:

- control selection
- indicator light requirements
- coding (symbology, color)
- panel labeling, lettering, and bracketing
- emergency control markings.

SECTION IV

EVALUATION OF DESIGN

4. INTRODUCTION

This section considers two additional human factors topics that are of concern in the technical approach documentation. The first topic is the test and evaluation requirements involved in the training device acceptance process. The second topic is the supporting research requirement. This concerns the identification and assessment of the research needed to provide technical solution for unresolved or high risk areas, described "in sufficient detail to relate technology or methodology improvement to the proposed training device" (NAVTRADEVCEN INST 3910.5). The issues in each of these areas are presented in detail in the remaining two chapters of this report.

4.1 TEST AND EVALUATION

This chapter provides guidelines for the human factors tests and evaluations to be performed throughout device fabrication to verify the suitability of the device as an instructional system. The theme concerns the development of the information requirements that must be satisfied to assure that the device performs as intended. The human factors effort subsumes a number of issues centering around the following:

- definition of the expectations and outputs of human factors instructional suitability testing.
- guidance on test plan design, time of accomplishment, and the documentation required.
- identification of the range of testing required and the methodology variations.
- indication of the specific tests and test series (by category) to be accomplished.

The human factors test and evaluation requirements described in this chapter are organized to provide inputs useful in the preparation of the performance specifications for a training device. The emphasis is placed on defining the information requirements for determining the capability of the device to support the desired training, and on procedures for test guide preparation and test execution (the what, how and when of testing). For example, information is presented which will enable the writing of precise specifications on the kinds of tests and evaluations and demonstrations to be accomplished by the contractor at defined points during device fabrication. (Currently, a Data Item Description, DD Form 1664, which supports line items on DD Form 1423, is used to specify a desired end product complete with instructions for preparation.)

4.1.1 Perspective. Testing of the instructional capability of a device progresses in an iterative sequence beginning with the early conceptual evaluation of design in the mockup stage at the factory and culminating in the exercising of the device as an integrated training system, on-site at the using facility. Further, human factors testing is conducted integral with the engineering suitability testing throughout the fabrication cycle.

Human factors testing should be designed to exercise the total capabilities of the device as a training tool. To achieve this, two basic types of testing and evaluation are accomplished in the device acceptance process. These are:

> Type 1--Static and part-system verification testing. This refers to continual time-programed factory testing of pertinent components and subsystems to verify the adequacy of the physical and the psychological environment for instructional purposes. The goal of these tests, evaluations and demonstrations is to identify, as early as possible in the fabrication process, deviations from the published device specifications or emerging discrepancies that will interfere with, or attenuate the instructional potential.
>
> Type 2--Instructional suitability testing. This refers to dynamic operational tests and evaluations to determine eventually that a device is instructionally suitable for accomplishing the defined training objectives. The testing, accomplished both at the factory and on-site, is geared to verifying the validity of the device for achieving the purposes of training.

Figure 35 places the human factors test series in perspective during the fabrication process. Since our purpose is to provide guidelines for design, no precise time frame is suggested for the testing series since the timing requirements are specific to any contemplated device. However, the schema is chronological, beginning with the preparations for conceptual demonstrations in the mockup phase and culminating in dynamic testing and evaluation once the device is delivered on-site. The human factors test series is correlated with the engineering suitability and acceptance test series; provision is made for periodic human factors review (as appropriate).

It should be noted that we are concentrating on a conventional approach, beginning with an examination of the design rationale and conceptual demonstrations and proceding to the on-site dynamic testing of the device as an instructional system. There are instances, however, where a device under procurement serves both as a training and as a research vehicle. In this case, the testing may require a problem solving approach (i.e., goals to be achieved) rather than a strict testing rationale since the

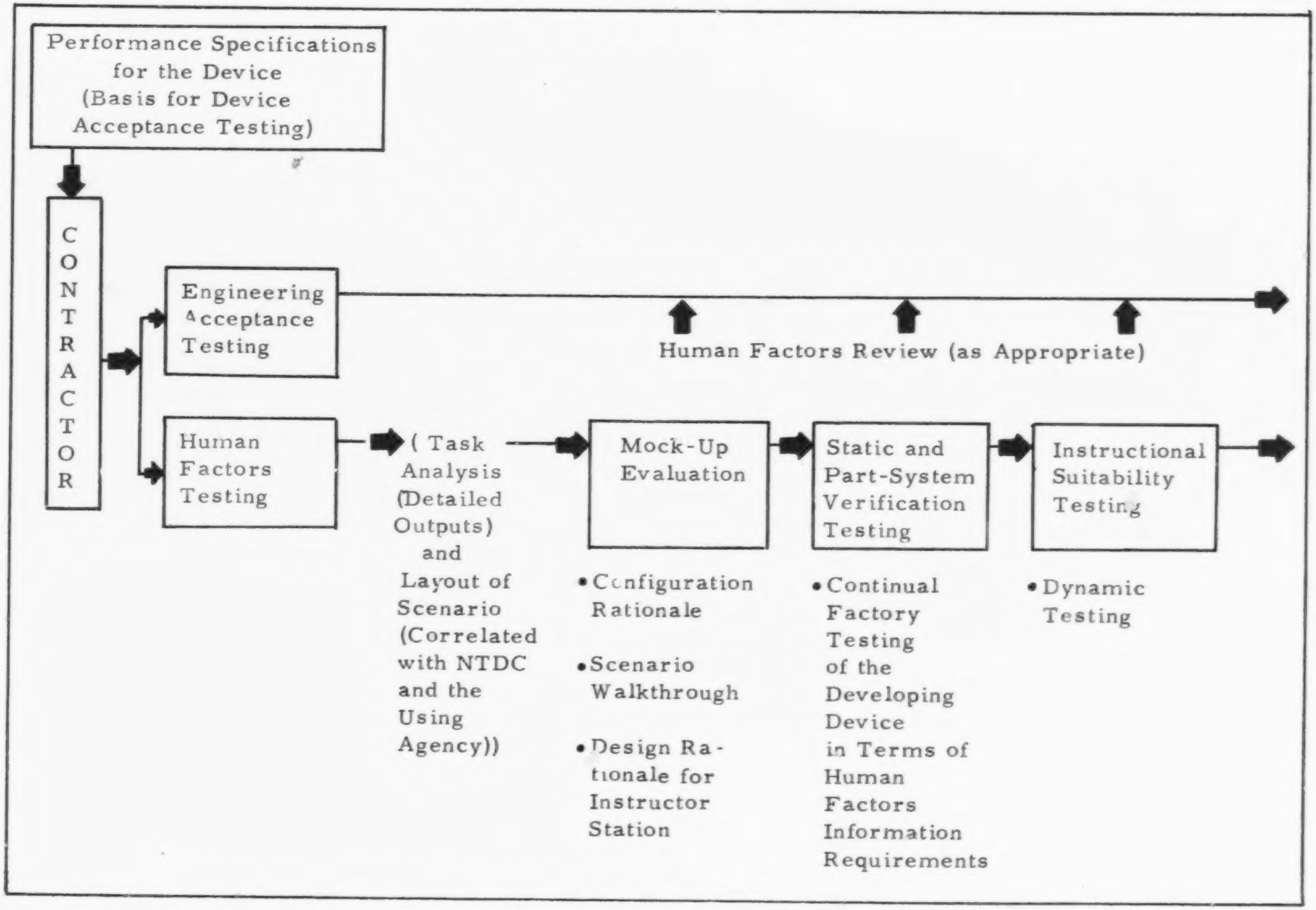


Figure 35. Human Factors Test and Evaluation Series Involved in Device Acceptance Process

device may not initially meet all the stated training and performance evaluation objectives. An example of such a situation is found in the suitability testing for Device 2B24, Synthetic Flight Training System. This device is unique to the Army since, it is not a replacement for existing equipment and the training possible with it has heretofor been unavailable to the Army. Testing which fails to build on the innovative features of this device would probably produce evidence of unsuitability to the Army's requirement. Conversely, testing which exploits the unique training capability of the device with the goal of determining its cost effectiveness in training could yield quite different results. A complete training program is currently not available with the device and substantial program development must be undertaken before the device is suitable for operational training (in this respect, Device 2B24 is a system under development). But suitability testing cannot be delayed until all of the desired automated programs are developed. Objective evidence must be obtained on the workability of the equipment, on the suitability of instructor station design and the approach to automated training, and on the instructional potential of the device and the manageability of the developmental work remaining. Thus, the suitability testing is geared to identifying the instructor station and automated training and performance evaluation features where adjustments may be indicated, while determining the suitability of the device independently of such adjustments. The testing series comprises three phases: Phase 1--determines in a gross sense, the workability of the automatic training features of the device; Phase II--develops an automated program of instruction (for use in the next phase) to test the training functions for which the device is intended; and Phase III--involves the conduct a transfer of training study to determine the training suitability of the device.

4.1.2 Approach. The testing and evaluation requirements throughout device construction are explicated next. Guidelines are provided for achieving the human factors contribution to the device acceptance process. Our approach is to organize the test, evaluation and demonstration requirements throughout device implementation to assure the delivery of an effective instructional tool. Details are provided on what must be accomplished in the chronology of device development within the conceptual-to-dynamic testing model outlined in Figure 35. Emphasis is placed on the content, methodology, and required outputs of the testing series. The material is presented in the generic context so as to be applicable to any of the more than twenty classes of training devices currently in the NTDC inventory. In addition, guidance is provided concerning the range and extent of human factors testing to be accomplished and the desired deliverable end products of testing. The data of this chapter should effectively support the writing of the test and evaluation requirements in the performance specification for a device by 1) providing the contractor precise directives for the human factors testing (by category) and documentation to be accomplished, and 2) installing a positive means of control of the acceptance testing procedure throughout device fabrication.

The remainder of this chapter discusses the test and evaluation requirements for:

- mockup review
- subsystem verification testing
- dynamic instructional suitability testing.

Also, a test plan format of general applicability is proposed for organizing the human factors requirements in the device acceptance process.

4.1.2.1 Mockup Review. The mockup inspection is the first formal evaluation phase in the development program; occurring prior to the fabrication of device components. By definition, it represents a closely knit coordinative effort between the contractor and the review board designated by the procuring agency. Essentially, the device contractor provides a mockup of the trainee station, the instructor and operator consoles and associated equipment, and an overall layout of the proposed device configuration. A mockup conference is held, wherein the contractor presents the design rationale and the results of the evaluation of the mockup. This involves a conceptual demonstration of the validity of the device as an instructional tool including a procedural "walkthrough" of trainer operations based on a representative script or scenario. The mockup and a mockup evaluation plan is provided in accordance with MIL H 46855 and the contract schedule.

Prior to the formal mockup conference, the contractor develops design information sufficient to insure a basis for the evaluation of the mockup components. Formal documentation is also identified in the specification. Characteristically, a trainer configuration report is specified which establishes a baseline for the mockup and review and, in final form, reflects the results of the mockup review. Updates are made via change sheets, as required. This report, specified via Data Item Description (DD form 1664) provides the design criteria and human engineering principles and practices to be applied in the design of the general arrangement of trainee and instructor stations, and the simulation and control equipment groups of the trainer. A representative example of such documentation is the Trainer Configuration Report for Device 1D23 (General Electric 1971).

4.1.2.1.1 Mockup Evaluation Plan. The mockup review is a static evaluation ("cardboard" representations, floor plan layouts, verbal demonstrations, documentation reports) which serves to verify the hardware design layout, the design rationale and instructional system operations. It provides a demonstration that the man-equipment combination can accomplish the required operations. The oral presentation by the contractor includes: a summary of the human factors analyses (trainee task analysis, instructor functions analysis, instructor CRT display formats and content, performance measurement routines, programed exercises, trainer modes of operation, and instructional control capabilities); a checklist verification of human engineering requirements; and a conceptual "walkthrough" (via a scenario) to demonstrate the adequacy of the design rationale and trainer configuration.

The specific information requirements that must be satisfied in the mockup evaluation plan are outlined next. The contractor provides the following documentation and oral demonstrations.

a. Human engineering checklist--Written statements are prepared which describe the relevant human engineering characteristics that effect the operation and use of the device. This forms part of the design rationale for the device in that all relevant characteristics are identified with a demonstration that compliance with these can be achieved. The checklist verification is accomplished in accordance with the design criteria published in MIL-STD-1472A and MIL-T-23991. The checklist identifies the human engineering essentials and the adequacy of the interrelations. The design issues, as appropriate to instructor and to trainee station design include the following:

- functional groupings of controls and displays
- anthropometry and workplace layout
- visual displays
    - illumination
    - information requirements
    - location and arrangement
    - coding
    - ease of use
- CRT displays
- indicator lights and legends
- auditory displays
- controls--layout and operability
- labeling

b. Scenario--A key feature of the mockup evaluation is a conceptual "walkthrough" of the procedures and sequences in the operation of the training system. This constitutes one portion of the oral presentation in the mockup review. Based on the training analysis data, a simulated mission scenario or an informal script of a representative exercise is developed for use in illustrating how the instructor console works and what interactions occur between the trainee and the instructor stations. The human factors emphasis in these "thought experiments" centers on the instructor station design and layout; little emphasis is given to the trainee station particularly when the station is a replica of the operational system (e.g., an OFT cockpit). The trainee station concern, however, increases as more general or universal training functions are provided. With generalized student stations, the concern includes: the trainee functions provided; the fidelity of simulation of key system components; the trainer modes of operation; the number and types of controls and displays and their locations; and, for multi-station trainers, the station configuration and instructor-to-student ratios.

The information requirements pertinent to the verification of the instructional operations of the device (at the instructor station) range across the following.

- instructor loading--instructor(s) handling of all available instructional options
- adequacy of instructor station layout
  - all instructional functions represented
  - ease of operation (face validity)
  - control and display groupings by functions performed
  - human engineering design (checklist verification)
- adequacy of accomplishing procedures and operations in all trainer modes (in the abstract, i.e., simulating the motions of performance, pointing, verbalizing, etc., in a step-by-step accomplishment of each instructional operation of the trainer).

The goal of the mockup review is the acceptance of the proposed final configuration of the trainer. Based on the contractor demonstrations, the procuring agency is able to:

- examine the layout and configuration of the training device and evaluate conceptually the "operability" of the instructional modes via a scenario walkthrough (modifications to the proposed design are documented in a defined end product for this phase of work, e.g., final Trainer Configuration Report for the device).

- adjudge the flexibility of software design to handle the available instructional options and enable off-line and on-line modifications as necessary.
- adjudge measurement routines, programed exercises.
- adjudge the adequacy and representativeness of the curriculum (e.g., mission scenarios) to be provided.
- determine the design adequacy for instructor station management.

With the completion of the mockup review and the acceptance of the proposed configuration of the training device, the static and part-system verification testing of the developing device is initiated. This phase is followed by the dynamic instructional suitability testing both at the factory and at the training site, which culminates in the acceptance of the training device for use in the operational training program. Each of these two testing phases is discussed next.

4.1.2.2 Static and Part-System Verification Testing. Subject to the approval of the mockup design review, the contractor establishes and conducts a human factors test and evaluation program to verify that the varieties of components involved in instructional system operation perform as intended. A series of tests are identified (by category) to be accomplished as soon as the required components have been fabricated and are available. This instructional suitability testing of the developing device is integrated with the engineering test sequences.

For the technical approach documentation, the goal is to identify the test plan requirements and to define the series of human factors tests to be accomplished. This input to engineering serves as an assist in the subsequent development of testing requirements in the performance specification for a device. (A generic test plan format which outlines the essential elements involved in human factors acceptance testing is provided in paragraph 4.1.2.1.4.) Thus, the human factors specialist is responsible for the following:

- definition of the relevant tests to be accomplished during the device fabrication cycle.
- definition of the performance requirements or the acceptable operations against which test outcomes may be compared.

The information requirements that must be satisfied during this continual factory testing phase are outlined next. Each test requirement in the series is undertaken as the equipment or component becomes available. Completion of the total series of part-system verification testing is the prelude to the subsequent factory and on-site instructional suitability testing of the device as an intact training system. The following tests (in terms of key issues to evaluate) are recommended to verify the instructional capabilities at the instructor console.

4.1.2.2.1 Human Engineering Design of the Instructor Station--The configuration and the panel layout of the station and the design of the displays and controls are evaluated iteratively based on the mockup design criteria and on any subsequent design changes.

4.1.2.2.2 Visual Displays--The operability and the use patterns of all visual displays at the instructor console are evaluated. The design issues to be examined include:

- location/orientation/viewing distance in terms of intended usage and frequency of usage.
- accuracy and legibility of the relevant formats.

4.1.2.2.3 CRT Displays--Tests are conducted of the computer-generated displays to verify that the essential information is provided for instructional purposes. The testing issues involve the verification of the following information requirements.

- flexibility of the display to provide all relevant information (student performance and error, problem events, scale variations, all problem/display modes)
- adequate information update
- rapidity of mode changes (during enroute monitor, control, and evaluation)
- accuracy, reliability and registration (information alignment) of the visual display(s)
- format requirements, pagination and page sequencing
- multi-formats--high density information display and integration; commonality of data locations

- continuous display and on-demand display of information

- legibility requirements.

4.1.2.2.4 Controls Used for Display Selection And Modification--The operability of controls associated with computer generated displays is examined for the following:

- compatibility of manual input means with CRT displays (e.g., keyboard, lightpen)

- versatility of display selection (all modes, specific events, error and status information, scoring information, page sequencing)

- initiation of desired actions (e.g., demonstration)

- modification of preprogramed scenarios (on-line).

4.1.2.2.5 Software Programing--Testing is required to verify the proper operation of automated instructional assists. The content of instructional programs is also evaluated (as appropriate). The pertinent software programing includes:

- the content and levels of difficulty of preprogramed exercises

- automated measurement routines (selection of measures and scores, combinations of scores, performance tolerance envelopes, modification of error criteria, performance sampling periods, forms of scores displayed, handling of excessive student performance errors)

- adaptive sequencing (adaptive variables, measurement, adaptive logic, display of the performance information)

4.1.2.2.6 Procedural Performance Display--Testing is required to determine the operability of computer-monitored displays of student procedural (checklist) performance. (An example of this type of instructional assist is the Trainee Monitoring System (TMS) which provides computer monitoring of checklist procedures in flight simulators.) The testing issues involve verification of the following.

- operation in all modes: on-line (problem mode) and off-line (daily readiness check, edit, replay, and change memory location modes)
- legibility of the CRT display
- demonstration of on-line operability (sequencing of procedures, identification of errors of omission/ commission, sequencing of CRT pagination (checklist of items), instructor intervention capability)
- operability of controls correlated with the display (function keyboard and overlays, cursor employment).

4.1.2.2.7 Hard Copy Production--Testing is conducted as early as possible to demonstrate the production of performance records. At this stage, the purpose is to generate hard-copy printouts, vis-a-vis the design rationale (i.e., error deviations, time and event recording, etc.), establish the information formats and verify the capability to call up or delete specific information. Examples of expected outcomes are shown in Figures 31, 32, 33 and 34 of this report. This operability testing is the prelude to the dynamic testing in the next phase which is concerned with the correlation between the information recorded and scenario events.

4.1.2.2.8 Off-Line Editing--Testing is conducted as early as possible to demonstrate the capability for off-line editing of programed scenarios. As with item 4.1.2.2.7, the purpose is to evaluate the capability to generate modifications to an existing program. An example of such an output is shown on page 110 of this report.

4.1.2.2.9 Specific Stimulus Presentation--Testing is conducted to demonstrate the capability to provide specific stimuli (messages displayed at prescribed times) which call for observable finite responses by the student. The verification testing issues involve:

- the presentation of a defined list of programed messages presented at precise times in an automated sequence
- student response capability to a message
- comparison of student response with the situation (the information requirements for programing include: system status information; vehicle position, movement, and direction; rates of resources expended, etc.)
- immediate presentation of knowledge of results.

4.1.2.2.10 Trainee Station Design--Tests are also required to verify the instructional capabilities of the trainee station. The emphasis is on the fidelity required for training and on the evaluation of "trainer peculiar" equipments (i.e., hardware and associated training functions not present in the operator stations in the actual system). Several tests for evaluating instructional suitability in the trainee station are recommended below.

a. Fidelity of simulation--Testing is conducted to verify that the fidelity of the stimulus or the signal simulation is appropriate to the purpose of training for a given device. In situations requiring high fidelity simulation, evaluations must be made by a pool of subject matter experts (employing an appropriate method of judging) that the information displayed is like that found in the operational environment or is judged as perceptually equivalent to the operational system. An example of the former is the electromagnetic signal environment (EW signatures); an example of the latter is motion simulation (in the OFT). In low fidelity situations, the evaluation (via an appropriate method of judgment) must verify that the level of simulation is adequate for achieving the desired training objectives.

b. Correlation of control inputs and display indications--Testing is required to determine the appropriateness of vehicle response to control inputs with instrument indications and visual display responses. In flight simulation, for example, vehicle response to control inputs may be evaluated by setting up defined flight situations and requiring expert pilots to make specific control inputs. Records are made of the instrument indications resulting from the variation of single control per trial. Consistency of device performance and verification of acceptable performance (with reference to defined tolerances) can thus be determined. In addition, the appropriateness of vehicle response to control inputs (handling qualities) can be evaluated via judgments made by experts (e.g., instructor pilots).

c. Trainer-peculiar equipments--Testing is recommended to verify the operability of equipments placed in the trainee station (not found in the operational system). These equipments, designed to enhance instructional capability, enable the student to initiate certain instructional events (demonstration, parameter freeze, etc.), or they provide useful information about his performance not found in the operational setting. The equipments evaluated include: closed circuit TV, trainee monitoring systems (computer monitored checklist events), annunciator panels (programed messages), problem control panels, and equipments providing visual indications of the immediate results of performance (knowledge of results).

4.1.2.2.11 Summary--The purpose of the testing series in this stage is to verify the operability of the various components and subsystems that influence the instructional capability of the trainer. This level of evaluation centers on contractor-testing of the operability of components and subsystems. Successful demonstrations at this stage serve to minimize the occurrence of discrepancies during the next phase, which is concerned with the instructional suitability testing of the assembled trainer.

4.1.2.3 Instructional Suitability Testing. The final phase of testing is begun at the contractor's plant when the training device is assembled, and is completed with the on-site acceptance of the device at the training facility by the procuring agency. This phase is devoted to operational suitability analysis and involves dynamic testing of the fully functioning system. In essence, this sequence of testing is accomplished to determine that the contractor has satisfied the performance specifications for the device.

The human factors evaluation (which is part of the operational acceptance testing procedure) is conducted to verify the instructional suitability of the device. The key feature is the employment of a simulated mission scenario (or exercise script) to demonstrate that the trainer, as an instructional tool, performs "as advertised." The test plan sequence is structured to exercise the system in an operational manner, and is therefore concerned with checking-out the scenario. The testing requirements and the evaluation sequences which follow are oriented toward training devices which employ a number of automated instructional assists for enhancing the training potential. However, certain tests are identified which pertain to devices wherein the setup, control and monitoring of the training exercise is accomplished manually.

4.1.2.3.1 Scenario Requirements--The preprogramed scenario should provide a training sequence (median level of difficulty) which exercises the key instructional features of the system. An alternative to this for flight simulation is to provide a standard checkride mission. In the case of devices wherein the training problems are manually installed and controlled at the instructor console, a test problem script should be utilized to specify the installation of the types of key events at prescribed times in an exercise (i.e., initial condition parameters setup, insertion of enroute problem events with appropriate display indications, and the insertion of emergencies and malfunctions).

4.1.2.3.2 Suitability Analysis--As described earlier, this phase of testing is designed to exercise the total capabilities of the fully functioning training system in order to demonstrate instructional suitability. "In situ" demonstrations are accomplished and judgments made about the following:

- the adequacy of the instructor stations displays and controls for the conduct of training.

- the extent to which a student or subject matter expert is able to proceed through each programed sequence in the scenario or accomplish the tasks or maneuvers installed in the device.

- the adjustments required in content, approach or design to facilitate accomplishment of training objectives.

In addition, the opinions of qualified operational personnel (instructor pilots, sonar and radar operators, etc.) provide additional information on the realistic nature of the installed events and on the handling qualities of simulated vehicles.

Each of the major human factors evaluations to be accomplished in the dynamic setting are identified next.

a. Instructor station operability--The requirement is to determine that the console(s) functions according to the contractor's documentation. The specific features include the following:

- all indicators, controls and display settings operate as specified
- operability of all communications links, intravehicle and external
- CRT displays and controls perform as demonstrated in the previous phase of verification testing
- operability of on-line instructional controls, and controls for off-line (utility) operations
- hard copy record production capability as demonstrated in the previous phase of verification testing.

b. Setup of initial conditions--The requirement is to demonstrate that the setup of initial conditions in an exercise (either programed, manual insertion, or via address of preselected data sets) produces the desired system states. This refers to the correctness of the initial conditions set up vis-a-vis the parameters and values selected (e.g., vehicle position, range, track, speed, etc., and environmental conditions).

c. Demonstration of the automated training features of the device--This testing is concerned with the hardware and the software programs that interface with training functions. The issue is to demonstrate that a subject matter expert (e.g., a proficient pilot) can begin at a defined programed entry point in a mission scenario and progress through the program to the intended exit point. The requirement is that the program performs as specified and causes the appropriate variations to occur as a function of the performer's actions. The validity of the programs may be assessed by 1) the opinions of the participating subject matter experts on the technical accuracy of the dynamically developing events in the trainee station, and 2) the judgments of human factors specialists on the validity of the content and presentation and on the instructional appropriateness of the sequence portrayed at the instructor console(s). The automatic training features to evaluate are recommended next.

- automatic scheduling programs--this concerns changes in the mission displays as a function of where the student is in the mission cycle. In flight simulation, representative examples include the automatic switching from cross-country to approach modes, and CRT pagination changes (e.g., automatic switching of air traffic control messages as a student proceeds through the scenario).

- automatic scoring--determination is made that the device is scoring and not scoring, as appropriate, via a correlation among the scenario time and events, the CRT performance and error display(s), and the hardcopy printout. This may be accomplished simply by requiring the student (or a subject matter expert) to deviate deliberately at prescribed times in prescribed ways, freeze the problem and observe that appropriate scoring information is provided.

- automated briefing, audio alerts, coaching messages--a demonstration is provided that all programs commence and end as scheduled as a function of student actions and the status of the mission.

- procedural (checklist) performance--an evaluation is made of the operation of computer-monitored checklist performance in flight simulators. This involves all off-line and on-line modes of operation, and includes assessing the display validity and the control operations for selecting procedures, sequencing the CRT pages and modifying the display. (See Chapter 3.4.8 on the Trainee Monitoring System (TMS).)

- specific stimulus presentations--determination is made that programed messages which call for specific student behaviors are displayed at specified times in the mission cycle. A sampling of messages is selected and the following assessments made: time of message onset as programed, length of time displayed, response evaluation (based on the response input from the trainee station) and adequacy of knowledge of results presentation. (See paragraph 3.4.6.3 on the annunciator panel.)

instructional options--tests are made concerning the flexibility in controlling the exercise requirements consonant with the development of an instructional strategy for each student. These evaluations center on the adequacy of the following:

- display of student performance and error information (as accrued) in all relevant instructional modes.
- selection of, and duration of the programed demonstration packages.
- control and display capability for remedial branching of the student (return to an earlier segment or maneuver for reinstruction).
- error alerts involving computer freeze of the problem when the student exceeds a preset error tolerance; capability for inserting modified error tolerances (Δ error) is also demonstrated.
- autopilot program is examined as a means for controlling task loading on the student and as a standard against which student performance may be compared.
- insertion of additional events/malfunctions in a programed scenario.
- capability in preprogramed scenario to manually override an event entry when it is position to enter.

- adaptive simulation--a demonstration is required that the adaptive sequencing performs as specified. The test points include the following: selection of the adaptive sequencing mode; task difficulty modification as a result of student control performance and the display of student performance information. The analysis involves a systematic introduction of changes in control performance (e.g., via a proficient pilot) to the scenario requirements as the basis for assessing the extent and speed of change in problem difficulty level. Judgments of difficulty level by a subject matter expert are utilized as well as objective indicants of change.

d. Malfunction programs--malfunction testing is accomplished across the range of programed or specified events to determine the following:

- each specific malfunction occurs correctly as programed or initiated (i.e., abrupt or gradual occurrence).

- the malfunction is reflected in appropriate instrument indications and in vehicle control.

- recovery from the malfunction can be accomplished with appropriate procedures.

- with similar malfunctions, discriminating cues are available to enable the student to identify the specific malfunction.

e. Off-line edit capability--an evaluation is made of typewriter routines for off-line editing of preprogramed problem parameters and for the generation of new scenarios.

f. Response characteristics of the simulator--an evaluation is made of the fidelity of simulator response characteristics to the operational system counterpart. This assessment is based on the performance of subject matter experts in the device. Judgments correlating the device performance with their experience in the real world model are used in this determination. The issues of concern include the following:

- handling and response characteristics of the device across the range of normal and emergency control situations provided in the scenario or script.

- visual attachment displays.
- atmospheric and environmental conditions (turbulence, windshear, engine and rotor sounds, etc.)
- weight and balance program for the vehicle.

In addition, trainer-peculiar equipments in flight simulators are evaluated for ease of use and for the adequacy of the information presented as an assist to instruction. These include:

- the provision of knowledge of performance information.
- closed circuit TV.
- annunciator display (specific message presentations).
- trainee monitoring system (TMS, which provides checklist procedures displays).
- problem control panel (means for student initiation of device events, such as: demonstrations, specific training exercises (in the automatic mode), problem halt, specific parameter freeze, motion system on/off, etc.).

4.1.2.3.3 Human Factors Test Plan. The test plan outlines the testing and evaluation emphasis to verify device design and to demonstrate that the device complies with the specified instructional suitability requirements. A generic format is provided in Table 17 which details the elements that must be accounted for (minimally) in an effective human factors verification testing effort.

TABLE 17. OUTLINE FOR HUMAN FACTORS TEST PLAN

a. Test or Test Sequence

1. Test identification and stage of testing
2. Purpose
3. Test objectives, concepts and requirements

b. Test Description

1. Summary of the test (initiation and end)
2. Emphasis (demonstration, evaluation, experimental test)
3. List of equipments involved
4. Number of tests to be accomplished
5. Special considerations

c. Factors on Which Performance Will Be Evaluated

1. Human engineering design
2. Occurrence of the instructional event or function
3. Verification of a procedural sequence
4. Time initiation, time latency, performance time
5. Response occurrence
6. Accuracy/error tolerance of system response
7. Flexibility in mode sequencing
8. Accessibility to displays, controls, equipments

d. Test Criteria and Measures

1. Criteria of test accomplishment
2. Objective measures (units of performance)

    - time
    - frequency
    - accuracy
    - discrepancies/errors
    - operability

3. Subjective measures

    - judgments, opinions
    - ratings

4. Points where measures are taken, frequency of occurrence
5. Reliability of the event, procedure, condition, etc., that is demonstrated.

TABLE 17. OUTLINE FOR HUMAN FACTORS TEST PLAN (Continued)

e. Test and Evaluation Instruments

1. Checklists
2. Rating forms
3. Questionnaires
4. Instrumentation
    - electrical recording
    - photography
    - graphic recording
5. Facilities required

f. Scheduling and Sequencing of Tests

1. Test scheduling (time)
2. Testing sequence and deviations
3. Conditions under which testing will be accomplished
4. Length of time each test or test sequence is observed

g. Data Collection

1. Data collectors (and number used)
    - subject matter experts
    - human factors specialists
    - other
2. Detailed data collection procedures
3. Conditions under which measures are taken or observations made
4. Number of subjects used
5. Number of trials or observations made (reliability)
6. Support requirements

h. Data Analysis

1. Events to be observed and judged
2. Relations to be tested statistically
3. Levels of assessment
    - demonstration
    - evaluation (expert judgment)
    - experimental test

TABLE 17. OUTLINE FOR HUMAN FACTORS TEST PLAN (Continued)

i. Data Usage or Purpose

1. Demonstration
2. Performance evaluation
3. Failure analysis
4. Verification of human engineering design of trainer
5. Verification of instructional suitability
6. Identification of potential training problems

j. Reporting Procedures

1. Report requirements

   - content
   - number
   - schedule

2. Results and conclusions
3. Failure/discrepancy reporting
4. Design recommendations

4.1.3 Summary. The human factors suitability testing is predicated on several key features.

a. Human factors testing is integrated with, and is conducted concurrently with the engineering acceptance testing.

b. Testing and evaluation is conducted on an iterative basis, by phases, and is accomplished as the equipments, system components and the completed device become available.

c. The testing, on a time continuum, is conveniently organized into three consecutive phases beginning with conceptual (paper and pencil) demonstrations in the mockup phase, progressing to static and part-system testing at the contractor's factory and culminating in dynamic instructional suitability testing both at the factory and finally at the training site once the device is delivered and installed. The discussion in Chapter 4.1 above describes the rationale for, and the sequences involved in the test and evaluation cycle.

d. The final on-site testing is a verification of the dynamic system tests conducted at the factory. In addition, the determination is made that the complete training system is performing to the specifications (i.e., for multicockpit trainers, all cockpits functioning and integrated in the management of the training).

4.2 SUPPORTING RESEARCH

In developing the technical approaches to the design of a training device, there are instances where the engineering technology is not adequate to achieve the precision required for effective instruction. These cases represent unresolved or high risk areas for design in that simulation techniques are not fully developed consonant with the instructional needs, or the feasibility of advanced engineering concepts has not be established. In the technical approach documentation, formal consideration should be given to supporting research requirements in these areas.

The human factors problem is that the information requirements tend to be ill-defined or inexact. Thus, additional research is needed to improve the human factors inputs to the engineering design in these high-risk areas. The human factors specialist should participate in identifying the design issues involved in maximizing instructional efficiency and in improving the information requirements against which candidate technical approaches may be compared. Research needs related to the information requirements for design may be conveniently grouped into three major categories:

a. Development of the human factors data base.

This concerns the definition of the simulation elements required to design subsystems in high risk areas including the development of quantitative values for parameters already defined. One major concern in this category is the development of design data on the perceptual cues needed for vehicle control simulation. An obvious example of this is the continued need for the examination of motion cues employed as surrogates for physical displacement of flight simulator cockpits, i.e., cues that have signal value and relevance to the real-world counterpart. This is presumably best accomplished within the current state-of-the-art by simulating the *g*-forces involved, utilizing: acceleration onset cues and washout of acceleration; acceleration scaling; and auxiliary signaling means such as pneumatic seat cushions, restraining devices and shearing force stimulation.

b. Quantitative techniques for evaluating technical approaches.

Development of quantitative techniques may be necessary for identifying and selecting engineering alternatives appropriate to specific design problems. An example of such a need is provided in paragraph 2.3.2 of this report which describes a technique for correlating candidate engineering solutions with simulation requirements.

c. New ways of viewing information requirements for design.

Specifying information requirements needed to support non-conventional approaches for enhancing training potential is also a research requirement. The emphasis here is to develop information requirements which will reduce the engineering constraints without compromising instructional effectiveness. An illustration of such a human factors research requirement is to develop an abstract depiction of cartographic information for radar landmass display, for example, representing a synthetic world instead of the real world (display of abstract entities such as a river, a cluster of artifacts, etc., instead of a named river, a named shoreline, etc., with their exact characteristics). With abstract depiction, real world cartographic information is not required, hence cartographic increments may be defined according to need.

4.2.1 An Example of a Supporting Research Requirement. Radar landmass representation in low altitude flight simulation is one example of an area which could benefit from supporting research. The currently employed factored transparency method of simulation suffers in certain respects due to optical problems and to the difficulty in controlling the size and shape of the flying spot (scanning). Resolution is limited by the combination of spot size, photographic grain size and optics; the limiting resolution is tied directly to the size of the problem area (Rubinoff 1971). Historically, factored transparencies have been adequate for high altitude mission requirements, providing a "birds-eye" view of a large area (e.g., 1500 x 500 mile area). However, for displays below 5000 feet, the information presented is too gross for training purposes. For low altitude flight, improvements are needed in 1) cartographic information (especially for hostile areas), 2) coding technique and 3) readout technique.

Continued research and development is needed to improve the precision of simulation. Various engineering development options are currently under investigation. One approach is to improve the factored transparency system. This requires a closely coordinated effort designed to improve all the relevant components of the optical chain. For example, it is not enough to simply reduce the photographic grain size even though the improvement, in itself, may be dramatic. System performance is determined by scanner spot size, spot brightness, sensitivity of the detector, and other factors, as well as photographic grain size. Therefore, all aspects of the system must be improved to a degree commensurate with that achievable in the least sensitive element.

A related but quite distinct problem is the choice of incremental units used to encode the basic data. Since the importance of terrain elevation is exaggerated at low altitudes, elevation data must be retrievable from the system in small increments. However, the required increments are often much smaller than those available from the usual cartographic sources.

Another promising approach is the digital simulation of radar landmass returns. Here, the photographic analog storage of terrain data is replaced by digital storage in a mass memory. Instead of a flying spot sweep over a transparency, the computer brings forth the appropriate data from memory in synchronism with the sweep. These data are converted to analog waveforms or profiles and then to radar return signal values. In digital simulation, resolution is not directly related to the problem area. This characteristic allows the exploitation of inherent terrain redundancies not feasible with analog systems. Also, the problem area need not be of fixed shape; it may be patched out of several base maps with almost unlimited flexibility. Patching of maps or installing dynamic effects is done under computer control (Rubinoff 1971). The primary problems of digital radar landmass simulation, however, result from the need to handle massive amounts of data, thus requiring tremendous computer capacity (i.e., nanosecond computing and gigibit memory).

In either case, applied research is necessary to specify the information requirements for simulating radar landmass returns for low altitude flight. Given good cartographic information and adequate readout and coding techniques, the human factors problem is to determine what cues are relevant in the low altitude context. The question is, what cues does the trainee extract in orienting to the terrain? At low altitudes radar reflectivity is quite different from that at high altitudes, and significant perceptual distortions occur (e.g., in shadowing, far-shore brightness, etc.). Techniques are not available for calculating these cues, thus, the need for behavioral study.

4.2.1.1 A Proposal for Supporting Research. An attempt to determine the cue requirements for low altitude radar displays is exemplified in an NTDC supporting research proposal. The required research which is outlined below, is intended to provide results for use in the design and specification of low altitude radar landmass simulation equipment.

Research Study

Visual extraction of geographic information from low altitude radar displays

Objective--The task is to define the characteristics of radar returns which enable a pilot or radar operator to orient himself to the terrain at low altitudes. The operational necessity for low level penetration of strike aircraft places increased emphasis on the use of radar information for navigation at altitudes of 200 to 1,000 feet. At the present time, there is no satisfactory solution to the problem of providing realistic simulated radar returns at such low levels. This is due in part to a lack of basic information concerning the value of certain typical returns as cues to the operator's orientation. This study will 1) investigate the returns of prominent terrain and cultural features as they appear at various combinations of speed and altitude (up to 1,000 feet), and 2) determine what radar cues are closely related to successful performance on the task of geographic orientation.

Approach--A small number of experienced radar operators will be asked to indicate their geographic orientation from cues derived primarily from the taped radar information (i.e., video tape recordings of an operational radar display flown over a prescribed ground track at various speeds and altitudes). Radar operators will be prebriefed on standard aeronautical charts and then asked to indicate their location and heading at irregular intervals based upon the dynamically displayed radar information. The cue-value of certain types of radar returns (e.g., far-shore brightening) will be evaluated by relating the subject's performance (in orienting himself in the terrain) to the display details being observed during or just prior to his decision. The tape will be stopped at the moment of decision and the subject will be asked to a) identify those features of the display which contributed to his decision, and b) estimate the degree of confidence to be associated with that decision. These data will provide a needed behavioral basis for engineering decisions concerning the relative priority of various radar returns which could be stored and retrieved in radar simulation systems.

The preliminary data derived from the debriefing techniques employed in this phase of study will be extended and refined by the more objective method of relating the display details actually being observed to the appropriateness of the individual decision. This technique requires accurate and continuous measurement of the subject's eye position in synchrony with the displayed video tapes.

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13. ABSTRACT

This report presents guidelines for achieving the human factors inputs to the Technical Approach in the training device design process. A method is provided which facilitates the correlation of instructional requirements with engineering design solutions. Techniques and procedures are recommended for organizing the information requirements which must be accounted for in the engineering design in order to maximize the instructional potential of a device.

Three major sections are provided. The first of these presents techniques and procedures for deriving the information requirements relative to achieving simulation fidelity in trainee station design.

The second section presents procedures for deriving the information requirements involved in setting up, controlling, monitoring and evaluating performance at the instructor station. Fourteen chapters describe the information requirements pertinent to the structure and control of training during off-line, pre-mission, enroute training and post-exercise operations.

The last section discusses the human factors test and evaluation requirements in the training device acceptance process. Procedures are outlined for verifying the suitability of a training device as an instructional system. The test, evaluation and demonstration requirements throughout device fabrication are organized to assist the human factors specialist in determining that the device perform as advertised.

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KEY WORDS

Lens Analysis
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Seidel Coefficients
Optics Program for
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Gauss-Seidel Method
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(c) to analyze a systems approach or results obtained from another source in a case a complex computer program is not available. General principles, on which this program is based, and all necessary details are explained. Instructions for the use of the program, several sample cases, and the program listings are included.

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